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Master Degree Project Final Report

"Design and manufacturing of a welding-jig for tailor-made bicycle frames"

MASCHINENBAU

Abstract

The handling behavior is a complex system influenced by many parameters. While many components can improve the comfort or performances of a mountain bike, the frame stays the main component that will define its handling. Indeed, as explained in this report literature review, each geometrical parameters of the frame influences greatly the bicycle handling. Every rider being different in anatomy or style of riding, it is necessary to adapt the frame to each rider to reach the best level of performances. The core of the tailor-made manufacturing of a bicycle is the positioning and holding of the tubes relatively to each other, a process that is carried via the use of a customizable welding-jig. This report analyses the current welding-jigs available on the market and describes in details the design and manufacturing of a unique welding-jig for tailor-made bicycle frame for Nicolai GmBH, a German company specialized in the manufacturing of high end bicycle frames. In addition, this report introduces the reader to an internet form listing all the combination of the bicycle industry's standards used by Nicolai GmBH. This internet form has for purpose to facilitate the understanding of the customer willing to buy a tailor-made bicycle frame.

The welding-jig has been designed on the Computer Aided Design software SolidWorks and is made of an assembly of Bosch Rexroth aluminum extruded profiles and their standard accessories and parts machined at Nicolai GmBH. Besides ensuring the positioning and holding of the different elements of a bicycle frame, it has the particularity to:

- Display every geometrical parameter of a bicycle frame.
- Be able to build a broad range of bicycle frame sizes.
- Give an easy access to all the parts of the frame to the welder.
- Reduce the number of aligning process in the manufacturing of a bicycle frame.
- Be easily movable.

This report presents also the calibration process of the welding jig and the description of its setting process. The welding-jig presented in this report has been tested successfully at Nicolai GmBH for the manufacturing of a hardtail bicycle frame. It is also highly appreciated by the technicians and engineer using it.

Sammanfattning

En mountainbikes köregenskaper är ett komplext system som påverkas av manga parametrar. Många av cykelns komponenter kommer påverka komforten och köregenskaperna, men det är ramen som är den mest centrala komponenten och det är den som kommer difinera dess köregenskaper. Som deet framgår i rapporten, kommer alla ramens geometriska parametrar kunna ha stort inflytande över dess egenskaper. Eftersom alla cyklister har olika anatomy och körstil är det nödvändigt att anpassa ramen utifrån individen för att maximera prestandan. Kärnan av skräddarsydd tillverkning av cyklar är kunna anpassa ramens rör I förhållande till varandra, en process som genomförs med anpassningsbara svetsjiggar. Denna rapport analyserar de svetsjiggar som finns tillgängliga på marknaden och beskriver I detalj designen och tillverkningen av en unik jig som tillverkas av Nicolai GmBH, ett tyskt företag som är specialiserade på tillverkningen av high-end cykelramar. Utöver detta introduceras läsaren till en internetsida som listar alla kombinationer av cykelindustrins standarder som används av Nicolai GmBH. Internetsidan har till uppgift att underlätta förståelsen för kunden som är villig att köpa en skräddarsydd cykelram. Svetsjiggen är designad I CAD-programmet SolidWorks. Den är byggd i Bosch Rexroth extruderade aluminiumprofiler, och deras standard tillbehör är tillverkade på Nicolai GmBH. Utöver att säkerställa att delarna hamnar på rätt position på cykelramen har den även följande egenskaper:

-Visa ramens samtliga geometriska parametrar.

-Kunna tillverka många olika storlekar av ramar

-Underlätta åtkomligheten av ramens alla delar för svetsaren

-Underlätta riktningsarbetet vid tillverkningen av cykelramen

-Vara enkel att flytta

Rapporten redovisar även kalibreringen av svetsjiggen och beskriver inställning processen. Den Svetsjiggen har framgångsrikt testats för tillverkning av en cykelram på Nicolai GmBH. Ingenjörer och tekniker som kommer att använda den är nöjd med resultatet.

Acknowledgments

I would firstly like to thank Karlheinz Nicolai, CEO of Nicolai GmBH and head of Engineering, for giving me the opportunity to carry my master thesis in his company, for the interesting project he decided to give me and for the trust he put in me for letting this project into my hands from its start to its end.

I would like to thank Marcel Lauxtermann, my supervisor at Nicolai GmBH, for all the knowledge he shared with me and his availability during the start of my project. I would also like to thank him for giving me the opportunity to travel to the United Kingdom with him and for the value he gave to my opinions about the company's products.

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Finally, I would like to thank all the employees from Nicolai GmBH for their warm welcome and for making me feel as a proud member of their family.

Contents

1 Introduction

Nicolai GmBH is a small German company founded in 1995 by Karlheinz Nicolai. This company manufactures high-end bicycles and provides a personal service to the customer unequalled on the market. Indeed, Nicolai GmBH offers, besides regular sizes, tailor-made bicycles regarding the geometry but also the aesthetic of the product such as different colors of anodization or powder-coating.

The current manufacturing process for tailor-made bicycle frames is problematic because the use of the current welding-jig increases excessively the workload on the engineer and technicians. Therefore, Mr. Nicolai planned to design and manufacture in-house a new welding jig for tailor-made bicycle frames.

A welding-jig is the tool used for positioning and holding the different components of a frame according to a control data that is the bicycle frame geometry. The aim of this project will therefore be to analyze the bicycle frame geometry parameters as well as studying the welding-jig designs already existing on the market for finally proposing an adequate design of welding-jig on the CAD software SolidWorks.

The manufacturing of this design will then be partly carried at Nicolai GmBH with the manufacturing processes and machines available and partly outsourced to suppliers. Finally, when assembled, the welding-jig will be calibrated at Nicolai GmBH and tested thoroughly to ensure its proper working. The project should conclude on the training of the technicians for the setting of the jig to ensure that all the knowledge gathered during the project has been transmitted and no questions are left unanswered.

2 Literature study

2.1 History of mountain biking

The bicycle is an invention nearly 200 years old and has evolved a lot during this period. In this section we will go through the mile-stones of the bicycle history to understand the background of this study.

The first report of bicycle looking machine goes back to the year 1817, when the Baron Drais invents the "Draisienne": two wheels linked together by a beam of wood. The propulsion of the Draisienne was made only by pushing on the floor with the feet, this led it to be referenced as the "running machine" [1].

Later, in 1861, Mr. Michaux transforms the Draisienne into the "Michaudine" by adding a more reliable steering system and propelling system via a bent axle: Mr. Michaux has just invented the crankset and the pedal.

In 1870, with the success of the "Michaudine" and the need for higher speed, the penny-farthing is born. This bicycle, first made in wood and later in steel, uses the pedaling system of the "Michaudine" on a bigger front wheel, which went up to three meters high to allow the rider to keep a relatively low pedaling frequency for the speed reached, thus causing some obvious safety problem for the rider and the pedestrians around.

To bring safety to the rider, the first diamond-shaped frame was created with the two wheels of similar size. However, the smaller front wheel required a transmission system to use efficiently the pedaling power. This led in the late 1880's to the first modern-looking bicycle, manufactured in Coventry, U.K. by Starley [2]. At this point, the bicycle had found its geometry but many improvements were to be made in the following years.

Indeed, in 1888, John Boyd Dunlop, a Scottish veterinarian, developed the first pneumatic tire for bicycle and later the rear free-wheel was invented [3]. With the free-wheel came the invention of the coaster-brake, increasing the safety of the rider. Some people where then starting to think about the possibility to use different gears.

In the early 1900's, the first rear derailleur is developed, allowing cyclists of the Tour de France to climb the Alps.

Until 1970, bikes were made only to ride on road as race or commuting machines but, finally, Gary Fischer, Tom Ritchey and Charlie Kelly started a company called MountainBikes, where they manufactured bikes based on a cruiser geometry with over-sized tubes, bigger tires and straight handlebar: the mountain bike was born. The mountain bike appealed to the sportsman searching adventure and more adrenaline. Even though at this time the main manufacturers did not follow the trend and concentrated their efforts on road bikes, the mountain bike attracted a lot of customers and big brands such as Specialized and Trek developed quickly. In 1989 the first suspension fork appears, followed finally in 1990 by a full suspension bike[4].

In the first decade of the 21st Century, mountain bike moved from an unusual sport to a mainstream one. In the last two decades, many technologies have been adapted to mountain biking such as disc brakes, gear boxes or composite materials but the main innovations are still made in the field of the transmission, the suspension and the geometry of the frame.

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[1] Frank Rowland Whitt and David Gordon Wilson. *Bicycling science*. MIT Press, 1993

[2] McGrory, David. *A History of Coventry* (Chichester: Phillimore, 2003)

[3] Frank Rowland Whitt and David Gordon Wilson. *Bicycling science*. MIT Press, 1993

[4] Mountain-biking. (2016, August,4). Retrieved from Wikipedia: https://en.wikipedia.org/wiki/Mountain_biking

2.2 Geometry of a bike frame

As we have seen in the history of mountain biking, the geometry of a bike frame has been the core of its evolution. Indeed, according to the C.O.N.I. manual, bike geometry is the base that will make a bike stable, easy to steer and comfortable [5]. In this section we will go through the basic elements of a mountain bike geometry, the different common terms used to define the handling and we will review some recent scientific articles aiming to understand the handling of a bike and to find the best frame geometry.
Firstly, as we have seen previously, bike frames are mainly designed around the diamond shape since the 19th century. This diamond shape involves two triangles: the front triangle and the rear triangle, joined together by the seat tube (see Figure 1). On a rigid bike frame, also known as hardtail, the front and rear triangle always stays in the same relative position (see Figure 1). However, in a suspended bike frame, the rear triangle moves relatively to the front triangle in order to allow the rear axle to follow a certain path (represented by the blue arrow in the Figure 1).

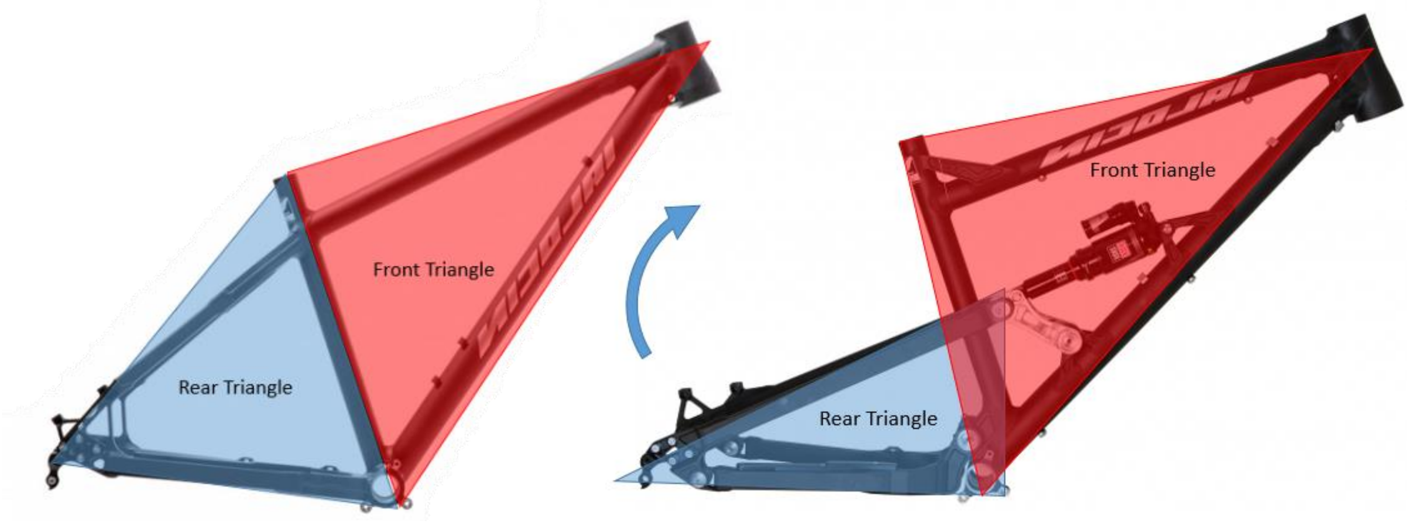

Figure 1: Front and rear triangles on hardtail and suspended bike frames.

Although nowadays many bikes may be made from hydro-formed aluminum tubes or composite shell, it is possible to describe every bike frame by an assembly of tubes as seen in the Figure 2.

[5] Federation of Independent Associations of Cycling, Italian National Olympic Committee, Central Sports School, *Cycling*, 1972.

Figure 2: Different components of a bicycle frame.

Every bike frame, would it be rigid or suspended, is defined by its geometry as seen in the Figure 3. This geometry is composed of angles and lengths between the main tubes of the frame and key-points such as the center of the wheels or the bottom bracket. Although some of the elements of the geometry might be defined differently by some bicycle manufacturers, the main elements are described as follow in the Table 1.

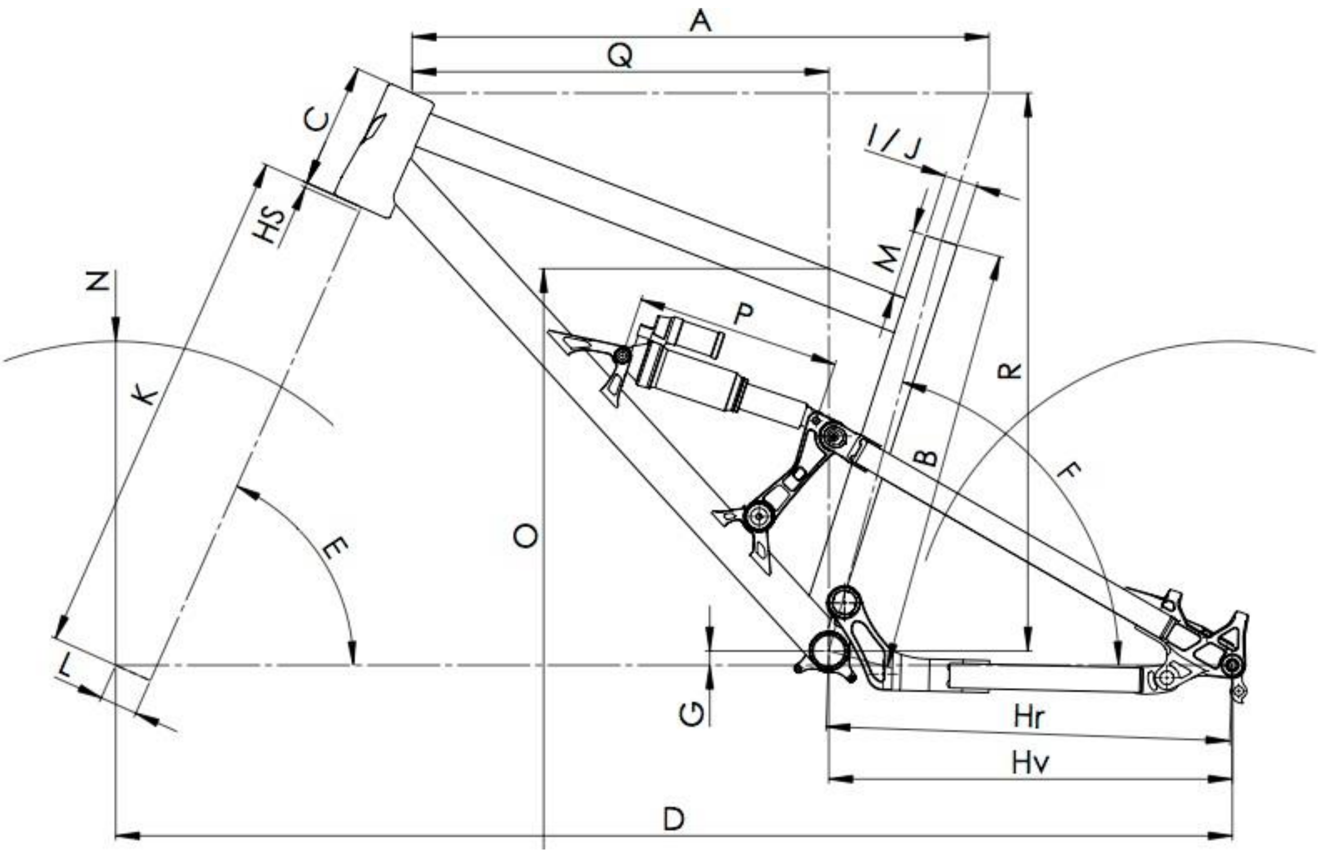

Figure 3: Geometrical parameters of a bicycle frame

	Geometry parameters	Additional description
A	Top tube length	Virtual horizontal distance between the top of the Head tube and the seat tube
B	Seat tube length	Distance between bottom bracket and top of seat tube
C	Head tube length	
D	Wheel base	Horizontal distance between the axles of the front and rear wheels
M	Seat tube offset	Distance between the top of the seat tube and the top of the top-tube at their intersection
O	Standover	Distance between the ground and the top of the top tube on a vertical line passing by the bottom braket
Q	Reach	Horizontal distance between bottom bracket and top of the head tube
R	Stack	Vertical distance between bottom bracket and top of the head tube
E	Head angle	Angle between the head tube and the ground
F	Seat angle	Angle between the seat tube and the ground
G	Bottom bracket drop	Vertical distance between the bottom bracket and the axles of the front and rear wheels
Hr	Chain stay length	Distance between bottom bracket and rear axle along a line joining the two point
Hv	Effective chain stay length	Horizontal distance between bottom bracket and rear axle
I	Seatpost diameter	
K	Fork length	Distance between the bottom of the head tube and the front axle along the axle of the head tube
L	Fork rake	Distance between the bottom of the head tube and the front axle along a right line of the head tube axle
N	Tyre diameter	
P	Shock absorber length	Distance between shock mount eye and shock lever eye

Table 1: Description of the geometrical parameters of a bicycle frame

In a suspended bike the path followed by the axle of the rear wheel is determined by the position of the pivot points between the chain stays, the seat stays, the front triangle and the shock lever as seen in Figure 4. The number and the position of those pivot points form what is called the suspension design of a bike.

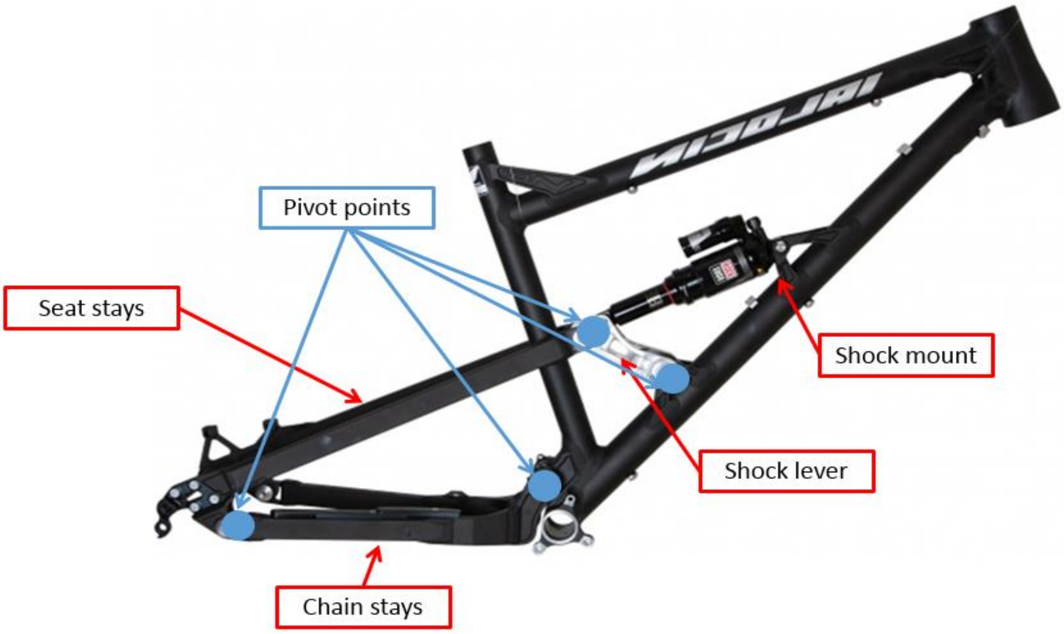

Figure 4: Example of location of pivot points on a suspended bicycle.

Many studies have been carried out to analyze the effects of a suspension system on the performance of the bike and the rider. Indeed, a rear suspension significantly increases the comfort by isolating the rider from vibrations and reduces his physical stress [6] Furthermore, suspension system can improve the handling of the bike, its stability at higher speed and its ability to keep traction while braking or cornering [7].

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[6] Henri Nielens and Thierry Lejeune, *Bicycle Shock Absorption Systems and Energy Expended by the Cyclist.* Sports Med 2004
[7] An Off-Road Bicycle with Adjustable Suspension Kinematics, S.A. Needle and M.L. Hull, *Journal of*

However, if it is easy to understand why a rear suspension might improve the performance and the comfort of a bike ride, it is necessary to understand that a suspension system may involve disadvantages such as higher weight or a dissipation of the pedaling power in the suspension system [8].

In order to reduce those disadvantages of the rear suspension on a bike frame, many suspension design have been created in the last decades. The most common design used nowadays in the bike industry are: the single pivot, the four-bar linkage with its variants Horst Link and Split Pivot, the virtual point pivot and the unified rear triangle (see Figure 5).

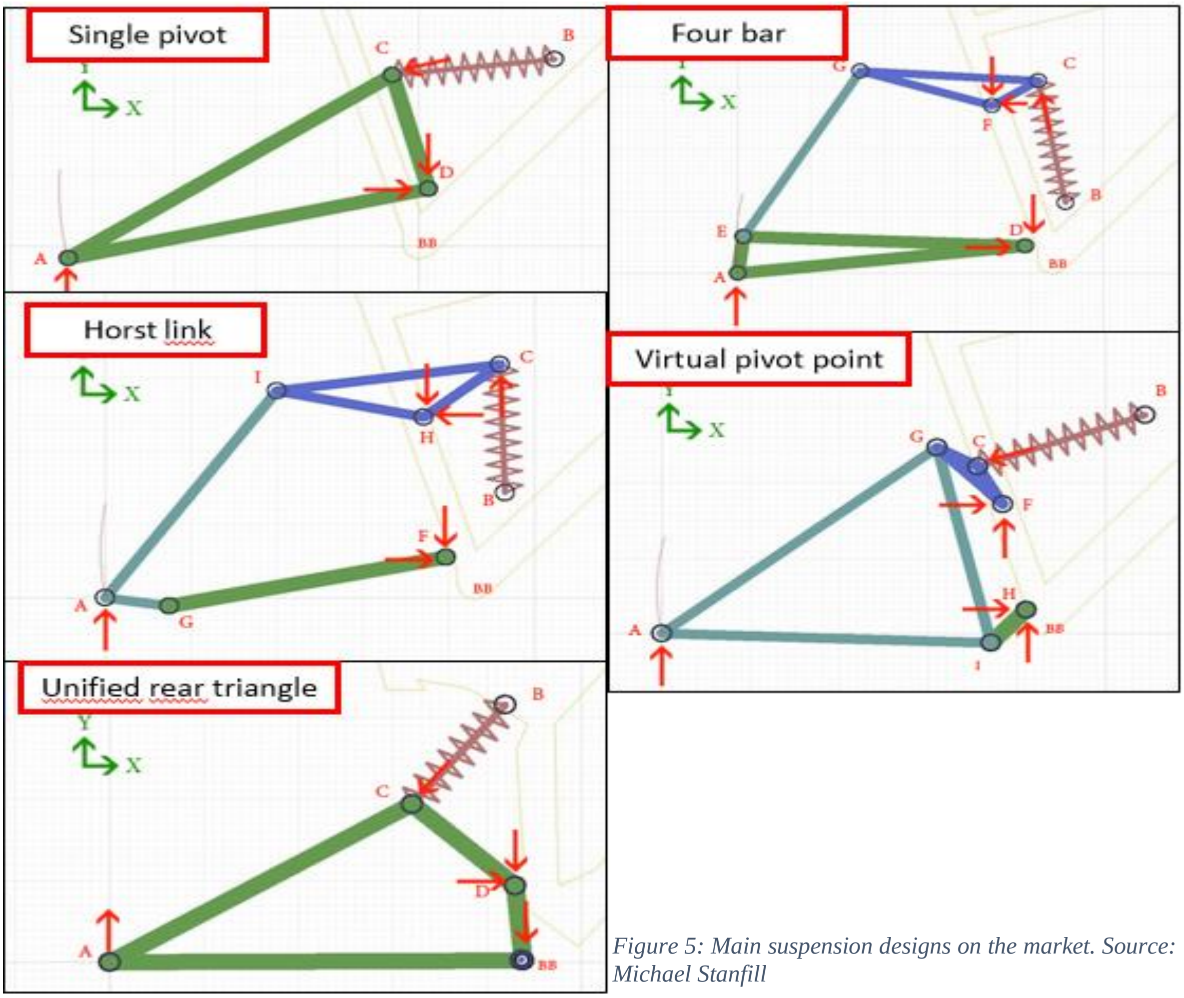

Figure 5: Main suspension designs on the market. Source: Michael Stanfill

If it is necessary to know the effects of a rear suspension on a bike's handling behavior, it is important to understand that a rear suspension design is efficient if only it is combined with a good frame geometry that will fit the rider's anatomy and type of riding. For the modern mountain bike, the number of parameters influencing its handling and performance is large. Indeed, every component can transform a bike ride in a pleasure or a nightmare. In order to make this review relevant to the subject of this project, we will focus in this review only on the geometrical parameters of the frame presented previously in the Table 1.

Mechanical Design, September 1997

[8] Ari Karchin and M. L. Hull, *Experimental Optimization of Pivot Point Height for Swing-Arm Type Rear Suspensions in Off-Road Bicycles*, Journal of Biomechanical Engineering, 2002

Unfortunately, as described by Wilson [9], the influence of each parameter on the bike's handling and the interaction between those parameters relies mainly on experience.

"The balancing and steering of bicycles is an extremely complex subject on which there is a great deal of experience and rather little science"

While many mountain bike magazines or websites such as Pinkbike.com or Vitalmtb.com review the bikes by their abilities to climb well or go downhill fast, a more scientific approach can be taken by describing a frame by its stability, its maneuverability and the position of the rider on it. On this subject, it is easy to find some experimental feedbacks from bike manufacturers or bike journalists in order to describe the influences of some of the geometrical parameters on the handling characteristics. [10]Simon Collis, in his complete guide to bike geometry on www.mbr.co.uk , April 2015, and Michael Zaho, in his article: "Geometry, an in depth explanation" on www.pinkbike.com, September 2009 [11], give us a good empirical overview of the effect of each parameters that can be summarized as following.

- Seat tube angle: A steeper seat tube angle brings the rider center of gravity forward over the bottom bracket. Therefore, allowing him to transfer more power in the crank and keeping the front wheel from leaving the ground in steep climbs. The bike becomes more stable and maneuverable in the climbs.

- Wheel base: A longer wheelbase will increase the stability to the detriment of the maneuverability. Indeed, a longer wheelbase make the bike more difficult to spin.

- Chain stays length: The chain stays length influences directly the wheelbase, thus influencing the stability and maneuverability. Short chain stays will make a bike easier to push and pull in holes or obstacles on the trail but will bring the center of gravity of the rider closer to the rear wheel, therefore increasing the probability of the front wheel leaving the ground in climbing conditions.

- Stand-over height: A lower stand-over height will allow the rider to move more easily on the bike. However, the stand-over is limited by the position of the top-tube that brings stiffness to the front triangle and the seat tube.

- Bottom Bracket Height: Bottom bracket height is very important when it comes to stability and maneuverability in corners. Indeed, by lowering the center of gravity of the rider and the bike, it allows the rider to keep grip on the tires while leaning in a curve. On the other hand, a bottom bracket too low will easily hit obstacles on the trails.

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[9] Frank Rowland Whitt and David Gordon Wilson. *Bicycling science*. MIT Press, 1993

[10] Simon Collis, *The complete guide to mountain bike geometry*, April 2015. Visited the 04/08/2016 http://www.mbr.co.uk/news/mountain-bike-geometry-326498#YVju8B4s68ZEwxJG.99

[11] Michael Zaho, *Geometry, an in depth explanation*, September 2009, Visited the 04/08/2016 http://www.pinkbike.com/news/bike-frame-geometry-2009.html

- Reach: A longer reach brings the front wheel further forward and increase the wheel base of the bike as well as leaning the rider forward.

- Stack: A longer stack brings the head tube higher. It is most of the time used in combination with the reach to define the different frame sizes and adjust the bike frame to the size of the rider.

- Head angle: With a steeper head angle, the steering becomes quicker and the climbing becomes easier because of the increased weight on the front wheel and so a better traction. However, a slacker head angle will increase stability of the steering and make descending easier by preventing the rider to go over the handlebar.

- Top tube length: The longer the top tube length, the longer the bike will feel on a seated position. However, the top tube length is less relevant in mountain biking because in technical sections along the ride, the rider is most of the time standing-up on the bike. Indeed, the top tube length is influenced by the seat angle, if the seat angle is low, the top tube length can be long but the reach can be short and therefore the bike can be very small for the rider in the stand-up position.

In order to prove scientifically what experience taught bike manufacturers and riders, many studies have been conducted to understand the dynamics of bicycles. However, those studies failed in simplifying the equations obtained and failed in correlating them to the design parameters in order to provide bike designers with a useful knowledge [12]. In his study, John Prince managed to create a model of the dynamic behavior of a road bike while steering and translated his results into four design charts. Those charts map the ideal steering geometry (head tube angle and fork rake), wheel properties (wheel diameter and moment of Inertia), frame geometry (position of masses, wheelbase and seat tube angle) and Mass and roll inertia of the bicycle. Even though the parameters' range of John Prince's study applies to road bike and cannot be correlated to actual mountain bike design because of the different position of the rider on the bicycle and the different use of the vehicle, this study is important for us to understand that a small variation of one parameter can lead to great differences in the bike handling.
In this section, we described the basic terms related to bike geometry and their influences on the handling of the bike using information collected from scientific studies and empirical knowledge. We will, in the next section, analyze how the geometry of mountain bike has been evolving in the last decade.

2.3 Evolution of mountain bike frame's geometry over the years

Mountain-biking is a relatively young activity when it comes to cycling, accordingly, mountain bikes took profit of the experience gathered in cycling to improve their designs. However, the technological development that appeared in the mountain bike industry the last two decades such as hydraulic disc-braking, hydraulic suspension and lighter materials allowed mountain bike riders to reach higher speed and riding more technical trails, thus

[12] John prince, *An investigation into bicycle performance and design*, July 2014

revealed a need to depart from the road bike geometry and develop mountain bike specific geometries and components [13].

Even though mountain biking can be separated in several distinct activities (see Appendix 1: Description of the different mountain bike disciplines.) most of the mountain bike frames have a lower head angle, longer wheel base, longer chain stays and longer top tube length than road bikes in order to fulfill the need of stability. However, since 2010, mountain-bike frames geometry has been evolving more quickly towards longer, lower frames and slacker head angle. In this section we will quantify this evolution via analysis of manufacturers' data and understand the mechanism behind this evolution with an interview with one of the pioneer in this geometry evolution, Chris Porter from Mojo suspension.

In order to highlight the evolution of mountain bike geometry on the market, a selection of 5 models from 5 different manufacturers have been selected. To have a relevant field of study, those five bike frames all correspond to the same discipline of mountain biking called "enduro "(see Appendix 1: Description of the different mountain bike disciplines.). According to the United States National Bicycle Dealers Association [14], in 2011, the three biggest actors of the bicycle market were Trek bicycle, Giant bicycle and Specialized bicycles. To broaden the study, three smaller but nonetheless renown manufacturers such as SantaCruz, Orange bikes and Nicolai have been selected. The six model geometries used in this analysis are:

- Specialized Enduro
- Trek Slash
- Giant Reign
- Santacruz Nomad
- Orange Alpine 160
- Nicolai ion 16

As we can see in Figure 6 those six mountain bikes have decreased their head angle with an average of 2.2 degrees. It is important to note that one degree of difference in the head angle can modify considerably the steering and handling of a bike [15]. Moreover, the reach and the top tube length have also considerably augmented in the past 6 years with a rise of respectively 16.3 mm and 31 mm. Accordingly, the slackening of the head angle and the increase in reach have led to a wheelbase longer of 56 mm. We can wonder why frame sizes have increased so much in such a short time, indeed, an increase of 16 mm in reach represent the increment between two bike sizes. If it is reasonably safe to assume that the average height of a mountain bike rider has not increased by 10 cm in 6 years (10 centimeters representing the height difference recommended between two bike sizes), we have to find another reason for this evolution.

[13] Frank Berto,*The birth of Dirt: Origins of mountain biking*,1999
[14]United States National Bicycle Dealers Association, *Industry Overview 2015*, 2015, Visited the 04/08/2016 http://nbda.com/articles/industry-overview-2015-pg34.htm
[15] John prince, *An investigation into bicycle performance and design*, July 2014

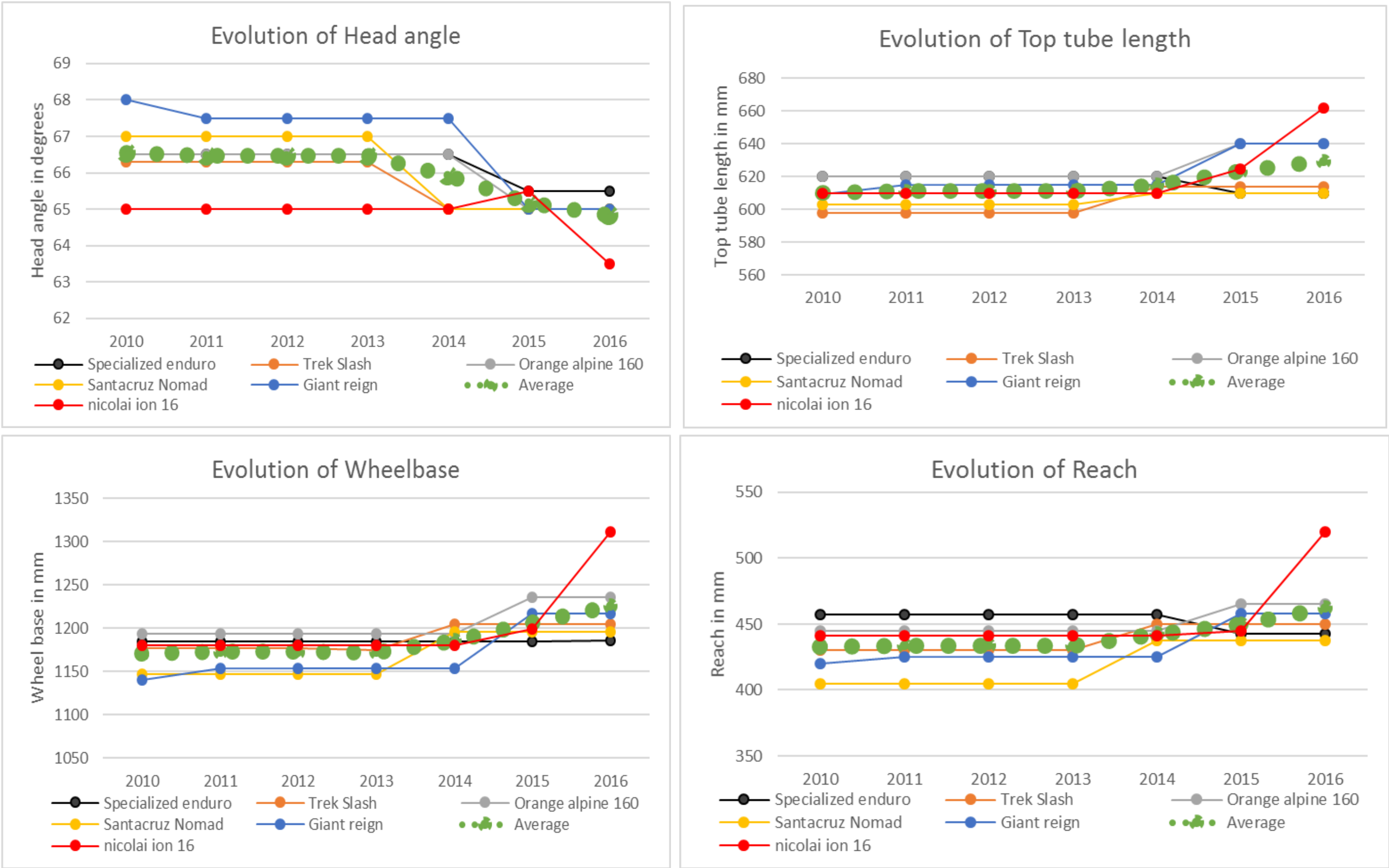

Figure 6: Evolution of Head angle, Top tube length, Reach and Wheelbase from 2010 to 2016 for Specialized enduro, Trek Slash, Santacruz Nomad, Giant Reign and Nicolai Ion 16.

In 2014, Chris Porter, Head of Mojo Suspension, the importer for Fox suspension in the United Kingdom, published a series of three articles about bike geometry on the website www.mbr.co.uk [16] [17]. In his article of the 16 May, Chris Porter highlight the fact that sizing in the mountain bike industry is irrelevant and only because inspired from road biking. Indeed, in road biking, between two sizes of frames, the seat tube length increases but the reach tends to be nearly identical and a longer stem is fitted on the frame, therefore bringing the handlebar forward and compensating for the taller rider. According to Chris Porter this technique works for road bike because the cyclist is constantly seated and therefore the weight on the front wheel is not sufficient for the rider to feel a drastic change in the handling capabilities of the bike due to the longer radius of steering. However, this system of sizing cannot be applied to mountain bike because of the standing up position.

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[16] Chris Porter, *Size matters: why we're all riding bikes that are too small*, 16 May 2014. Visited the 04/08/2016 http://www.mbr.co.uk/news/size-matters-why-were-all-riding-bikes-that-are-too-small-321374#LKlYffotBavUwG8X.99

[17] Chris Porter, *Size matters part 2: Finding the limits of geometry and sizing*, 14 August 2014. Visited the 04/08/2016 http://www.mbr.co.uk/news/size-matters-part-2-finding-limits-geometry-sizing-323289#zUj9co2RDLdcfPF4.99

In this article, Chris Porter deplores that mountain bike manufacturers still follow the road bike sizing by increasing the reach between sizes half as much as the seat tube length, leading to bad positioning on the bike for tall riders, which can produce back pain or a feeling of falling over the handlebar in steep sections. More than only bringing problems to light, Chris Porter experimented with bike geometry and proposed in his second article of the 19 August 2014 a series of improvement made on current market bikes. In his quest for a better bike-geometry, Chris Porter contacted the German bike manufacturer Nicolai GmBH in order to build a tailor-made frame with measurements not common at this time such as a head angle of 63 degrees instead of the 66 degrees available on most bike, a bottom bracket height of 330mm instead of the average 350mm or a chain stay of 450mm in comparison to the most commonly used 435 mm. Conducting timed training and combining the times obtained with his feelings on the bike as well as feedbacks from other riders, Chris Porter concluded that the Nicolai bike he was riding was a milestone in the evolution of bike geometries.

By his experiment with bike geometries, Chris Porter is considered as one of the pioneer of the “lower, longer, slacker “trend in bike design. During my stay at Nicolai GmBH in Germany, I had the opportunity to travel in March to the United Kingdom in order to meet Chris Porter as well as Jack Reading, a professional downhill mountain biker racing for the Nicolai One Vision Global Racing Team, the World-cup level racing team sponsored by Nicolai GmBH. Knowing the point of view of Chris Porter on bike geometry, I decided to ask him several question while riding concerning the bicycle he had at this time and his approach in riding it. [18]

As described by Chris Porter in the interview reported in the Appendix 3 : Interviews of Chris Porter and Jack Reading this radical change in geometry requires the rider to modify his riding technic in order to ride faster than with a conventional geometry. If this geometry allows normal riders to become more confident in downhill and more stable in climbs, it was interesting to discuss the influences of the new geometry on the results of a professional rider. During my professional trip to United Kingdom, I had the opportunity to sit with Jack Reading, top rider of the One Vision Global racing team and ask him few questions about the new geometry [19]: In the interview reported in the Appendix 3 : Interviews of Chris Porter and Jack Reading, Jack reading confirms that the new geometry improved his results and confidence on the bike. However, this new geometry requires a better fitness of the rider in order to take full advantage of it.

Have Chris porter and Nicolai GmBH defined the reference for the future of mountain biking geometry? If many riders seem confused by this drastic changes from the conventional road-bike inspired geometry [20], it is interesting to notice than some manufacturers such as SantaCruz bicycles followed the movement and are now offering new

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[18] Interview conducted the 13th March 2016 in Llangollen, Wales.
[19] Interview conducted the 14th March 2016 in Delph, England.
[20] Paul Aston, *Jack Reading's Nicolai GeoMetron DH - Lourdes DH World Cup* 2016, 10 April 2016. Visited the 04/08/2016 http://www.pinkbike.com/news/jack-readings-nicolai-geometron-dh-lourdes-dh-world-cup-2016.html

sizing and geometry that fits the taller rider [21].

In this section we had an overview of the evolution of mountain bike geometry over the last years and we had an insight on the development of the “longer-lower-slacker” geometry that is starting to change the view of bike manufacturers on bike design.

2.4 Existing welding jig designs

In this section we will study the existing welding jig designs in the bike manufacturing industry. I will analyze the different designs used for mass production or tailor-made designs and I will discuss their pros and cons.

Bike manufacturing is a growing industry, between 1970 and 2006, the worldwide production of bicycles has doubled. Indeed, according to the Earth Policy Institute, 53 million were produced in 1990 against 106 million in 2006 [22]. With such a production rate, it is important to differentiate the manufacturers producing high-end bicycle from the manufacturer producing bike for hypermarkets. In this study we will focus on the manufacturing of high quality mountain-bike.

As in any manufacturing industry, a company wants to make high profit. In order to do so, a bike frame company has the choice of manufacturing a large number of bikes at a low cost and needs to have a large share of the mountain bike market, or, a company can choose to manufacture a smaller quantity of bikes and sell them at a higher price.

Most of bicycle manufacturers focus on the mass production approach and therefore use fixed welding jigs. This approach requires the manufacturers to produce bike frames at the lowest unit cost possible that still guaranty the quality and performance of the product. To do so the manufacturer needs to have a high rate of utilization on each process, a low inventory and a reduced variability in the finished product. This is why manufacturers such as Specialized, Trek, Giant, Commencal and many others outsourced their production to Asia and particularly to Taiwan, where the workforce is qualified and trained to fulfill the quality requirements of high-end bicycle frames. To limit the number of variants to produce, those manufacturers offer every model in four different sizes in average: Small, Medium, Large and sometimes extra-large. This limitation in the range of sizes allow them to define and set precisely a set of geometrical parameters for each size of bike frame and accelerate the building process.

[21] Olly Forster, *Behind the Bike: Developing the XXL Santa Cruz V10*, 5 June 2016. Visited the 04/08/2016 http://www.pinkbike.com/news/behind-the-bike-developing-the-xxl-santa-cruz-v10-2016.html

[22] J. Matthew Roney, *Bicycles Pedaling into the spotlight*,Earth Policy Institute, 12 May 2016

As described by M. Menard, head of Research and development department at Commencal Bicycles, in his documentary on the production processes involved in the development of a bike frame, most companies use a template jig [23]. This template jig is set with the geometrical parameters of one size for one model and will ensure the positioning and the locking of the tubes relative to each other. In Figure and Figure , we have an example of template jigs used in the production of some of the Nicolai bike frames.

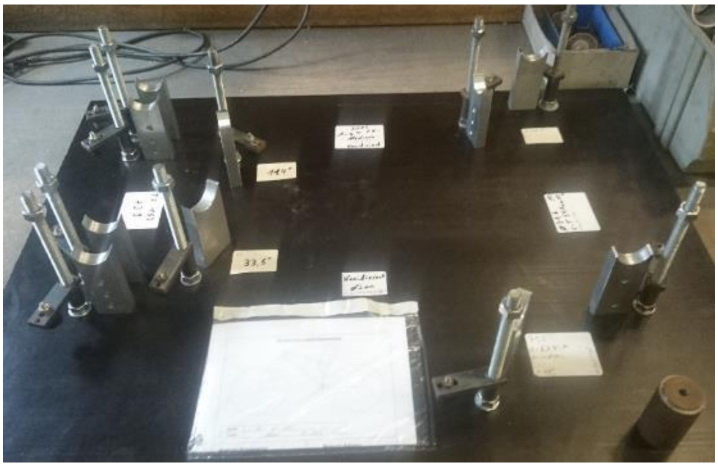


Figure 7: Template jig at Nicolai GmBH without tubes

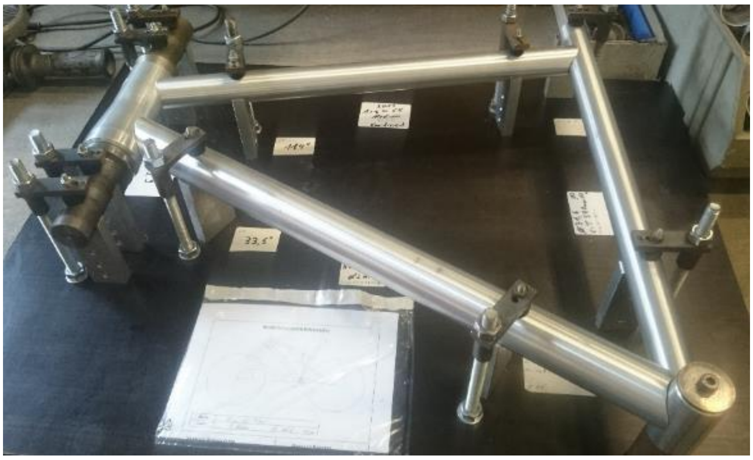


Figure 8: Template jig at Nicolai GmBH with tubes

A template jig has the advantages of ensuring the same positioning for each bicycle frame produced. Indeed, as the jig is set, calibrated and not modular, the variance between two frames is greatly reduced compared to a modular jig where plays in all junction influence the precision of the system. Another advantage of a template jig as discussed before is that the operator in charge of positioning the tubes does not waste time setting it and thus increase the productivity. Moreover, a fixed geometry and fixed jig allows for a better automatization of the whole production process. All the tubes can be cut in an up-stream process without verifying previously the angles and length on the template jig and still ensure a tight adjustment between tubes required for the TIG welding process.

However, a template jig is by its definition set for one geometry corresponding to one size of one model. In a mass production approach, a manufacturer will need several templates of the same size and model to produce multiple frames at the same time and satisfy the customer demand. Because bicycle manufacturers offer more than a dozens of different models in 4 sizes (data collected from websites of manufacturers: Canyon, Commencal, Specialized, Giant) [24] [25] [26] [27], it is easy to understand than the template jig system requires an important number of jigs to produce, store and modify at each modification on the geometry.

In a different production system, bicycle manufacturers focus on the high variability in the product they offer to the customer and thus have a lower production rate and a higher selling cost. To be able to produce bike frames with high variability, a bicycle manufacturer can allow the customer to select between:

- Pre-defined sizes or tailor made geometry
- Different cable holders

[23] COMMENCAL Insiders: META V4 Prototype Building, https://vimeo.com/125942279, 27/06/2016
[24] http://www.trekbikes.com/ Visited the 04/08/2016
[25] https://www.canyon.com/en-se/ Visited the 04/08/2016
[26] https://www.specialized.com/se/en Visited the 04/08/2016
[27] https://www.giant-bicycles.com/sv-SE/ Visited the 04/08/2016

- Different components interface
- Different finishing process for the frame (Anodizing or color painting)

The final positioning of the tubes relatively to each other has to fulfill the geometrical requirement imposed by the size selected but also has to be compatible with the components standards such as (see Appendix 2 for description of a bicycle and its components):

- Wheel size standard
- Crank size standard
- Headset standard
- Brake mount standard
- Seat post standard
- Rear shock size standard
- Chain guide size standard

Therefore, if a bicycle manufacturer decides to offer a high customization of its product, it is necessary to be able to modify easily and precisely the geometry of the bike frame. In order to so, bicycle manufacturers can build their own welding jig or purchase one from companies specialized in manufacturing of bicycle welding jigs.

The number of bicycle welding jig manufacturers is small in comparison with the number of bicycle frame manufacturers, indeed, most of bicycle frame manufacturers use fixed welding jig or build their own tailor-made frame welding jig. We will therefore focus on the main three manufacturers of welding jigs: Anvil Bikeworks, Sputnik tool and Henry James. In the following sections, we will analyze one welding jig of each manufacturer and compile the pros and cons of those three designs.

2.4.1 Anvil Bikeworks: Type 4

Anvil Bikeworks is considered by professional bike builders as the best bicycle welding jig manufacturer. The Type 4 is the high end model of welding jig offered by this company based in the United States of America. As seen in the Figure 7, the welding jig design is based on a machined plate that forms the structure of the jig and on which are translating or rotating different interfaces frame/jig.

In order to avoid any thermal deformation or deterioration of the metal surface during the welding and to keep the weight of the jig low, the main plate and positioning members are made in black anodized Aluminum 6061 T6. However, all the contact points with the frame are made of type 630 stainless steel (also known as 17-4 stainless steel, see Appendix 4: Description of 17-4 PH steel). Moreover, all scales are machined with laser to resist the damage from the heat while welding and all the positioning members are movable via quick-release levers or lead screws for a better precision and ease-of-use. In addition, the Type 4 possess vents for gas back purge during welding of steel or titanium frame. Finally, Anvil Bikeworks offers the possibility for the welder to combine its Type 4 welding jig with a stand allowing him to turn the jig 360 degrees around an axis parallel to the bottom bracket in order to get access easily to every part of the frame.

The range of modularization available is described in Figure 8.

SPECIFICATION	ADJUSTMENT RANGE	
	MIN	MAX
Head Tube Angle (degrees)	60˚	80˚
Head Tube Height (mm)	220	568
Head Tube Length (mm)	55	340
Seat Tube Angle (degrees)	60˚	80˚
Seat Tube Length (mm)	200	700
Top Tube Length (mm)	296	639
Bottom Bracket Drop (mm)	-65/-80	+110
Effective Chainstay Length (mm)	225	506
Bottom Bracket Shell Width (mm)	64	122

Figure 8: Range of modularization of Anvil Bikeworks Type 4
Source: http://www.anvilbikes.com/

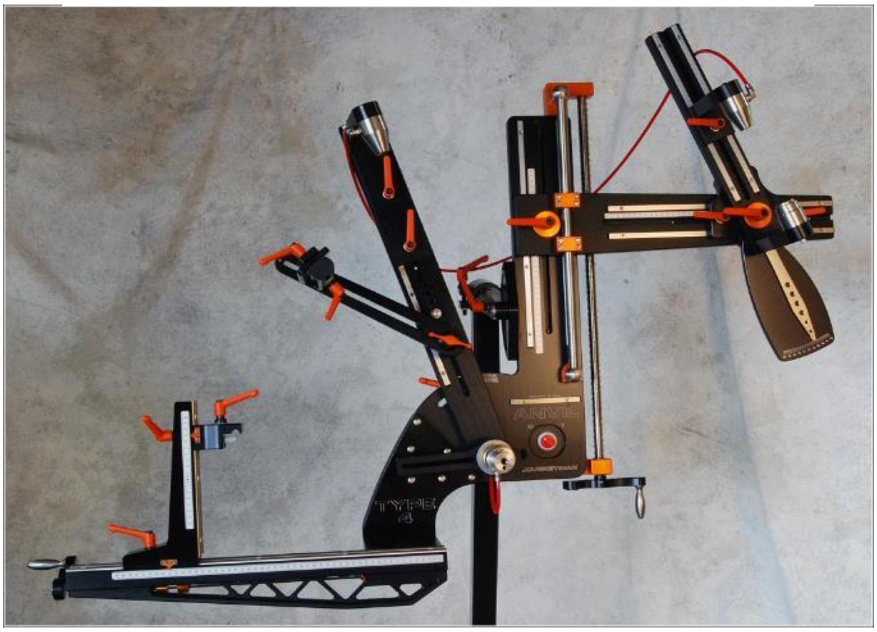


Figure 7: Anvil Bikeworks Type 4
Source: http://www.anvilbikes.com/

As we can see in Figure 7, the Type 4 offers the welder to read directly on the jig the geometrical parameters such as:

- Chain stay effective length
- Bottom bracket drop
- Seat tube angle
- Seat tube length
- Head tube angle

However, we can notice that no device allows the frame-builder to set directly the reach, the stack or the top-tube length on the jig as the top head-tube cone is not always located along one of the axis of translation. (see Figure 9). Moreover, the Type 4 does not provide any support to hold the top tube nor the down tube nor the chain stays while welding.

Anvil Bikeworks welding jig Type 4 is available at $5400 without the compatible stand and is delivered with two axles to hold the drop outs and two interfaces for head-tube as seen in the Figure 9.

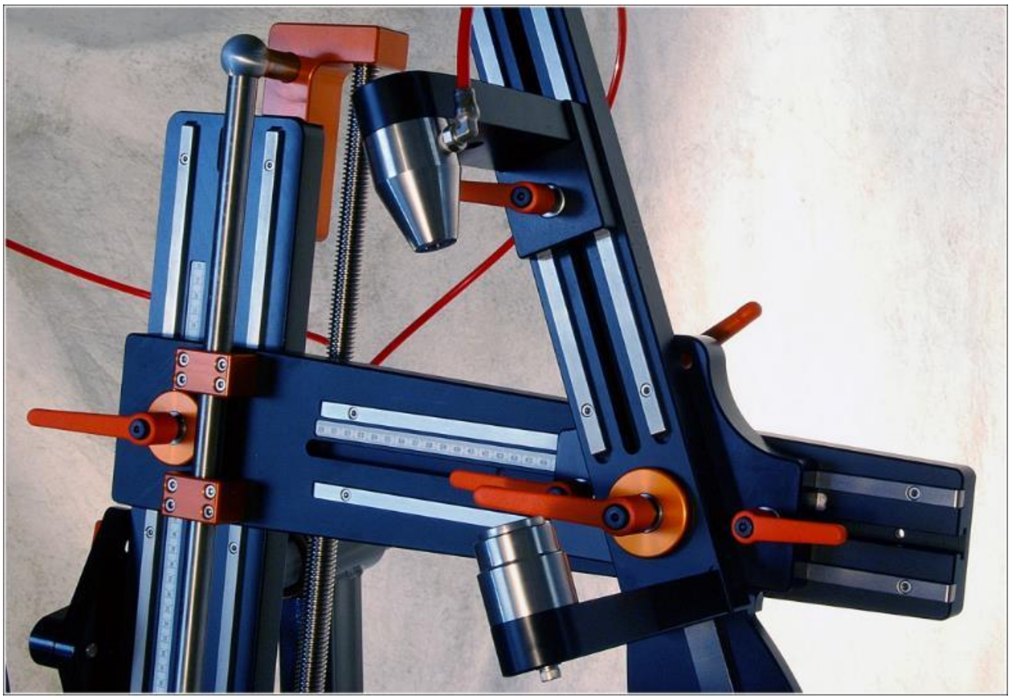


Figure 9: Head tube holding unit for Anvil Bikeworks type 4
Source: http://www.anvilbikes.com/

2.4.2 Sputnik tool frame fixture

Sputnik tool is a US based company specialized in the tooling for bicycle frame building. Sputnik tool offers one welding jig for the manufacturing of bike frame represented in the Figure 10 available at $5250. As we can see in Figure 10, the Sputnik tool frame fixture relies on the same architecture as the Anvil Bikeworks welding jig. An aluminum black anodized plate is used as reference for the design and positioning and holding elements are translating or rotating on this plate. All the contacts between the jig and the frame are made out of stainless steel. Adjustable plates hold the seat stay and the chain stays to center them along the center line of the bike.

Figure 10: Sputnik tool frame fixture
Source: http://www.sputniktool.com/

As said before, the Sputnik tool welding jig presents an architecture very similar to the Anvil Bikeworks apart from a bigger aluminum back plate, the holders for the chain stays and the absence of lead screws for the setting of the vertical translation of the head tube. Therefore, the Sputnik welding jig presents the same position of the scales and allows the welder to set up quickly:

- Chain stay effective length
- Bottom bracket drop
- Seat tube angle
- Seat tube length
- Head tube angle

Figure 11: Head tube holding unit of Sputnik tool frame fixture
Source: http://www.sputniktool.com/

However, according to Jeff Buchholz, the man behind Sputnik tool, it is possible to read directly on the jig all the geometrical parameters without having to use any rulers or formula. Even if this statement is well-founded for the geometrical parameters stated above, the Sputnik tool cannot display the value of the reach nor the value of the stack nor the value of the top tube length. Indeed, the architecture of the head tube motion does not place the top of the head tube as the center of the pivot joint for the head angle as seen in the Figure 11. Therefore, the head tube angle and the seat tube angle influences the reach, stack and top tube length and they cannot be read directly on the jig as claimed.

Finally, the top tube and down tube holders requires a bigger dimension of the back plate. Thus increasing the weight of the jig and reducing the access to the frame for the welder.

2.4.3 Henry James Universal Jig

Henry James is another company based in USA specialized in tools for bicycle builders. Henry James offers two welding jig, the access 65 and the Universal Jig at $4100 on which we will focus.

Figure 12: Henry James Universal jig
Source: http://www.henryjames.com/

As we can see on the Figure 12, the Henry James jig also offers an architecture using a back plate in aluminum on which positioning members translate or rotate and on which clamping devices are fixed.

However, the Universal Jig does differ from the Anvil Bikeworks and Sputnik Tool jigs regarding the holding and setting of the seat tube. The seat tube is not placed in position via a cone on its top but is clamped between the top tube and down tube. This design allows for a smaller back plate and therefore liberate space for the welder around the connection between the seat tube, the top tube and the seat stays. On the other hand, this connection does not provide any measurement for the seat tube angle or the seat tube length. The Henry James welding jig provides direct measurement for:

- Chain stay length
- Bottom bracket drop
- Head tube angle.

The henry James welding includes a bridges and boss fixture that ensure the good positioning of the brakes fixation on bike frames not using disc brakes. Regarding the welding options, the Henry James does not provide gas vents for back purging.

2.4.4 Conclusion on existing welding jig designs

The welding jigs available nowadays on the market of tailor-made bike building follows a vertical architecture where an aluminum back plate is used as reference for the motion of the contact points between the jig and the frame. This design allows a greater rigidity of the jig and ensure the alignment of the frame around its center line. However, this design reduces the access to the frame for the welder.

As tailor-made jigs are most of the time used to weld steel or titanium frames, those jigs present gas vents for back purging. They are also designed to weld entirely the frame on the jig and not only designed for tacking tubes together.

Finally, regarding the setting of the jigs, we can conclude that all the jigs analyzed do not offer settingof all parameters related to the real geometrical parameters used to define a bike frame. Indeed, none of the studied welding jig display the fork length, fork rake, reach, stack or top tube length that are all important parameters for the definition of a geometry.

3 Nicolai GmbH - company, products and processes

3.1 Nicolai GmBH history

Nicolai is a German bike company created in 1995 by Karlheinz Nicolai which is now located in Lübbrechtsen, a small village in the countryside of Hannover [28] .

The story behind Nicolai GmBH started in 1991 when Mr. Nicolai started his practical training for AMP-research in the United States of America and was involved in the development of the suspension design called Horst Link. Back in Germany, Karlheinz Nicolai receives in 1995 an order from Mongoose for the design manufacturing of one thousand frames. He then proceeds to produce all the frame with two colleagues in his father's garage with a conventional turning and milling machine. In 1996, the Mongoose designed by Karlheinz Nicolai wins the USA national downhill series.

Fresh from his success and encouraged by colleagues for whom he had built specific bikes, Mr. Nicolai decides to start his own company the same year, in 1995.

The history of Nicolai GmBH is then marked by milestones of success such as the 4th spot as the most innovative manufacturing brand in Germany in 2000 and the win of the ISPO DuPont BrandNew Award in 2001 as the most innovative startup.

The particularity of Nicolai GmBH lies in its manufacturing processes. Every product branded Nicolai GmBH is made in Lübbrechtsen, Germany, while all the bicycle manufacturers outsources their production in Asia. This allows the company to shorten the cycle from Research and Development to Production and brings the best innovations to the customer.

As well as being known for the quality of its welds, Nicolai GmBH is a pioneer in the development and implementation of gearboxes on mountain bikes. In 2004, the G-BOXX project is revealed to the public and since then, Nicolai GmBH has been always offering a bicycle with a gearbox in its range.

Nowadays, Nicolai GmBH produces around 1100 frames per year and is one of the leaders in the current geometry revolution happening in the Mountain bike world. Indeed, with the design of the Geometron, the company is ahead of everyone in the "longer, slacker, lower" geometry design. Even though being so successful, Nicolai GmBH manages to still represent the hand-crafted touch of the bicycle industry that attracts the rider in quest of exoticism and customization.

[28] Data collected from interview conducted with Karlheinz Nicolai during the project and from the website http://2009.nicolai.net/company/e-history.html visited on the 04/08/2016

3.2 Actual frame production processes at Nicolai GmBH

Bicycle frames can seem easy to produce, but the requirements of the high end bicycle market and the processes involved in the production, such as welding makes a bicycle frame more difficult to produce than we think. Indeed, bicycles have to be light, reliable and perform well. Requirements that forces a manufacturer to have a precise control on each of the processes involved in the production and forces him to control and ensure the quality of each product.

As the brand signature of Nicolai GmBH is to provide customize customer support, it is logical that the company stayed on the path of aluminum frames. Indeed, in comparison to composite manufacturing that involves the utilization of molds that cannot be modified easily, manufacturing of aluminum brings reliability and easy control over the processes. The material used in the manufacturing of the frames is the alloy 7005 (see Appendix 5: Composition of 7005 aluminum alloy).

Nicolai GmBH is one of the last manufacturers to be truly considered as making hand-made bicycle. If the terms hand-made relates to a certain level of craftsmanship, Nicolai GmBH takes a real industrial approach in the making of their frames which are renown as manufacturing and engineering pieces of art. In this section, we will follow the production of a Nicolai Hardtail frame in order to understand all the parameters that influences the final quality of the product. Through the description of the processes, we will also describe the differences between the manufacturing of a hardtail frame or full suspension frame.

3.2.1 Machining

Nicolai bike frames are manufactured entirely from straight tubes or profiles non-butted and raw aluminum machined parts that connects the different tubes or profiles together. For every model a set of those connection parts are to be designed and machined. On every bike, the machined parts are:

- The head tube:

Originating from a raw aluminum tube, the head tube is machined in a lathe for the contour and inside diameters. Finally, it is milled in a 4 axis machine for the Nicolai Logo. The head tube inside top diameter is machined at 44 mm and the bottom one at 56 mm.

Figure 13: Raw aluminum tube for head tube.

Figure 14: Finished Head tube

- The bottom bracket unit:

It represents the connection between the seat tube, the hoof and the yoke while assuring that the dimensions respect the bottom bracket bearing and the chain guide standard sizes. This part is critical in the design of a bike as it is under loads from the weight of the rider, the pedaling forces and can be subject to shocks on rocks or trees.
At Nicolai, the bottom bracket unit of a hardtail frame is turned on a lathe and the hole is milled on the 4 axis machine (see Figure 15). On a suspended frame, the bottom bracket unit is machined from a raw aluminum block due to the complexity of the design. Indeed, a suspended bike requires an offset in the seat tube position regarding the bottom bracket in order to allow enough clearance for the rear wheel during the compression of the suspension. (see Figure 16).

Figure 15: Bottom bracket unit of a Nicolai hardtail frame

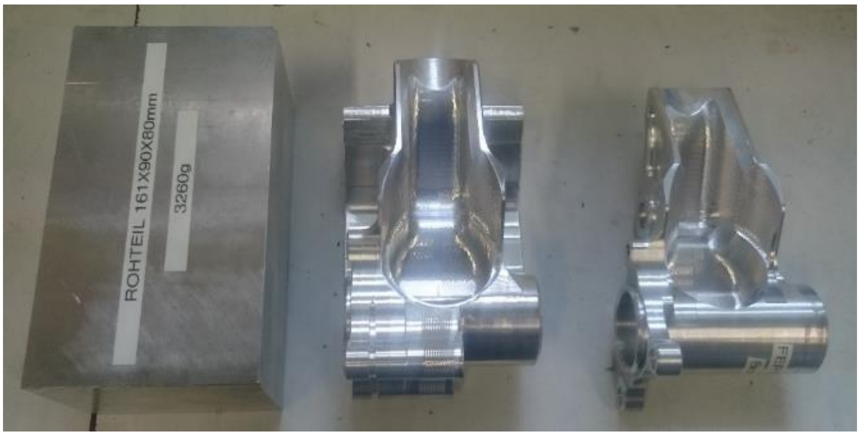


Figure 16: Three different steps of machining a bottom bracket unit for suspended frame. From left to right: Raw block, first milling, Finished part

- Drop out:

The drop outs connect the chain stays to the seat stays while assuring the position and the length of the rear axle. At Nicolai, the drop outs are machined from a raw aluminum block on a 4 axis CNC machine. The right and left drop outs are not identical, indeed, the left drop out has to ensure the positioning of the disc brake caliper on the frame and the position of the rear axle in the frame while the right drop out has to hold the derailleur hanger (hanger for gear shifting mechanism) and ensure the tightening of the rear axle on the other side of the frame.

Figure 17: Left: Right drop out with interface for derailleur hanger
Right: Left drop out with holes for disc brakes

- The yoke:

The yoke is the link between the seat stays and the seat tube, it has to leave enough clearance for the tire to pass between the two seat stays and ensures enough rigidity for the rear triangle while riding and cornering. At Nicolai GmBH, the yoke is manufactured following the H.W.T. technology.

H.W.T. stands for Hollow Weld technology that consists in welding two half shells together. This process is difficult and cost intensive but it allows to produce lightweight, stiff and durable parts.

As seen in Figure 18, the two shells are machine from a raw block of aluminum and welded together afterwards.

Figure 18: Two half shells of a yoke for Nicolai Argon frame

Figure 19: Welded yoke of a Nicolai Argon frame

- The Hoof:

The hoof ensures the liaison between the chain stays and the bottom bracket. As the Yoke, it has to leave enough clearance for the tire to pass in the frame and it rigidifies the rear triangle. The hoof is also manufactured using the HWT process which allow it to be rigid enough while leaving enough clearance for the crank arms to rotate around the bottom bracket for pedaling.

The two half-shells (see Figure 20) are machined on a 4 axis CNC machine from a raw block of aluminum.

Figure 20: Two half shells of a hoof for Nicolai Argon frame

Figure 21:Welded hoof of a Nicolai Argon frame

- The Gussets:

The gussets are metal plates used to reinforce some critical points on the frame. Indeed, there is some concentration of loads around the head tube and the seat tube junctions. To avoid the weld to crack and in order to rigidify the frame, Nicolai GmBH uses gussets at the junction of the head tube/top tube/down tube on hardtail frames. In order to rigidify the front triangle on a suspended frame, gussets are also used at the junction seat tube/ top tube.

Figure 22: Head tube gusset

Figure 23: Seat tube gusset

Figure 24: Down tube gusset

3.2.2 Mitering of the tubes and positioning on the welding jig.

After all the machined parts are ready to be assembled, an operator selects the appropriate template jig for the model and the size to be produced and places the machined parts into the jig. At Nicolai, the template jig used concerns only the front triangle of the frame, independently from being a hardtail or suspended frame (see Figure 25).

Figure 25: Template jig for front triangle of a Nicolai frame

The machined parts define the reference for the tubes to be mitered at the right lengths and angles. Therefore, the operator will miter the tubes according to the angle defined on the template jig and verify the plays between the machined parts and the tubes for the welding. This operation is long and difficult because the plays need to be as small as possible to ensure a good weld. The order followed for the mitering of the tubes is the following:

- Top tube at head tube junction (see Figure 26).

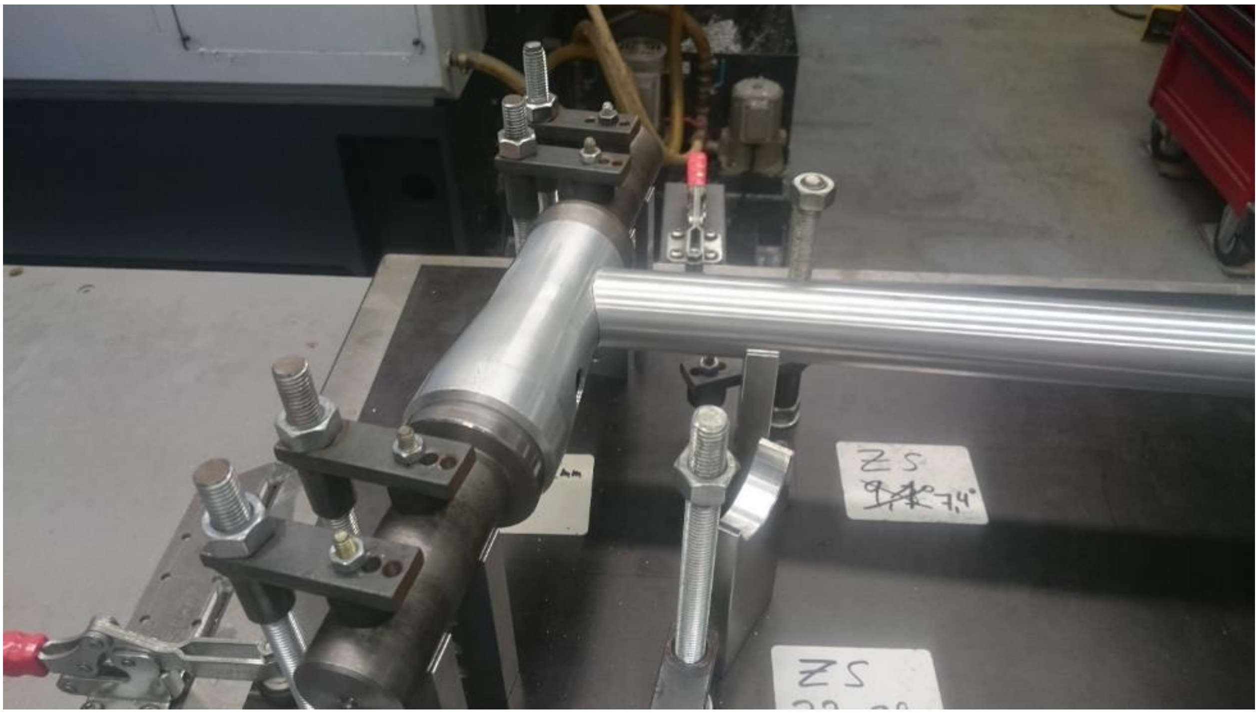


Figure 26: Junction of head tube and top tube on a Nicolai frame

- Down tube at head tube junction (see Figure 27).

Figure 27: Junction of head tube and down tube on a Nicolai frame

- Top tube at seat tube junction (see Figure 28).

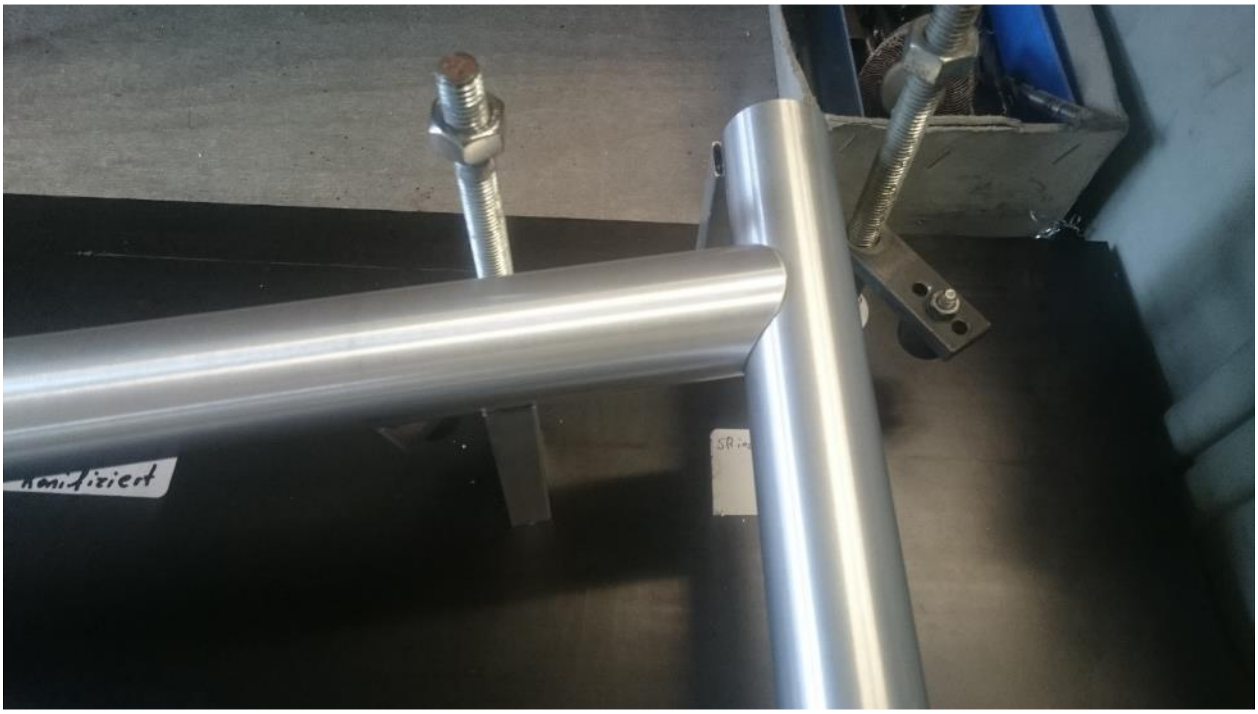


Figure 28: Junction of seat tube and top tube on a Nicolai frame

- Down tube at bottom bracket junction (see Figure 29).

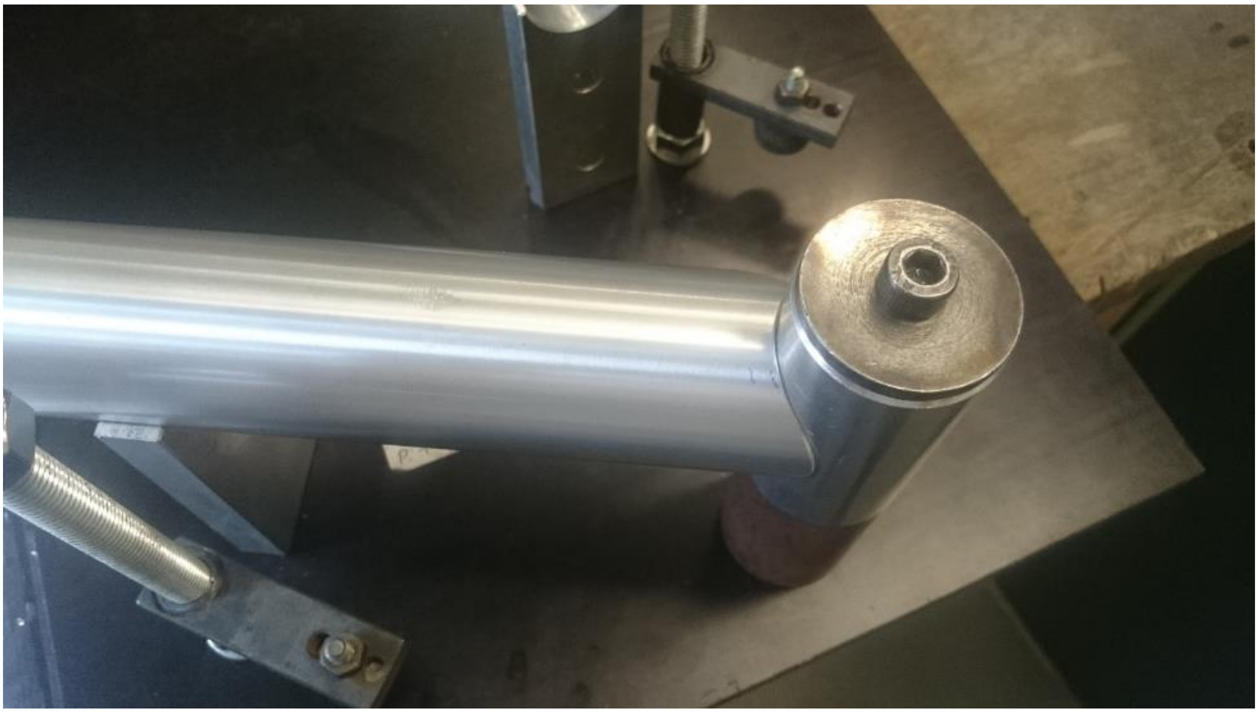


Figure 29: Junction between down tube and bottom bracket on a Nicolai frame

- Down tube at seat tube junction (see Figure 30).

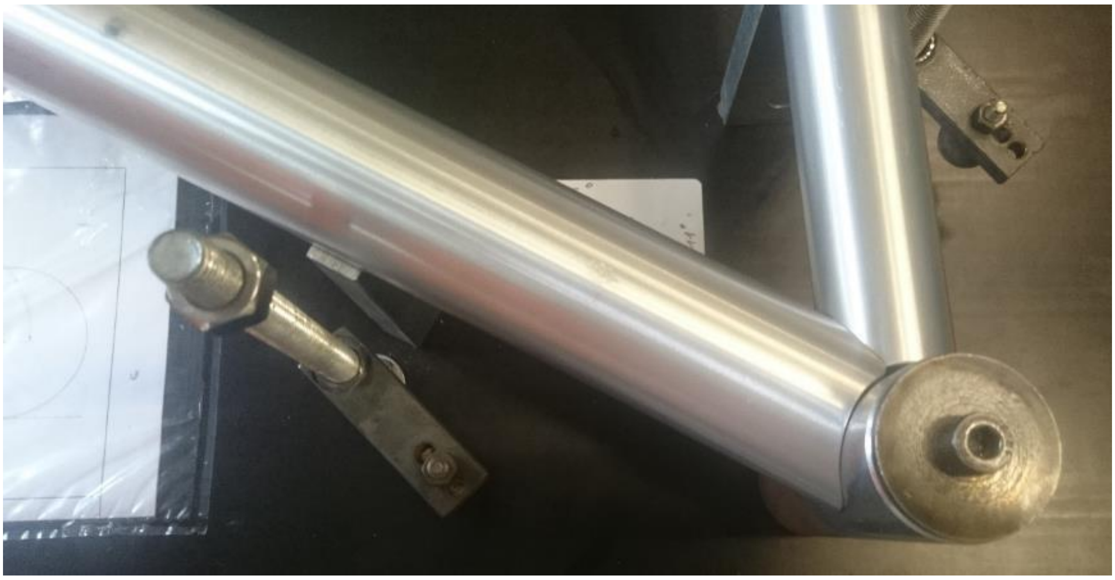


Figure 30: Junction between down tube and seat tube on a Nicolai frame

- Seat tube at bottom bracket junction (see Figure 30).

After the tubes have been all cut at the appropriate length and tested on the template jig to respect the plays for the welding, the operator place and maintain the tubes on the jig with the head tube and the bottom bracket unit. Once all the tubes are fixed to the jig, the operator brings the assembly to the welder.

3.2.3 Tacking front triangle.

The main back plate of the template jig reduces the access to the welding zones for the welder. In addition, the number of template jig being limited at Nicolai to one jig per size per model, it is necessary to make it available as soon as possible for the operator responsible of the tube positioning. For those reasons, the frame is only tacked by spot welding on the jig and will be welded entirely out of the jig.The tacking guarantees that the geometry imposed by the jig is kept when the frame is removed from it.

The tacking and welding of the frame is done by TIG welding (Tungsten Inert Gas) using alternative current source, AL MG 4,5 MN (EN-AW 5083) metal filler (see Appendix 6: Description of metal filler used in the welding of the Nicolai Frames) and Argon gas.

Figure 31: Tacked front triangle of a Nicolai frame

Figure 32: Details of a tacked head tube on a Nicolai frame

3.2.4 Welding front triangle without gussets or shock mounts.

After the tacking process, the frame is removed from the template jig and the welder start the complete welding of the front triangle. At this stage, only the head tube, down tube, top tube, seat tube and bottom bracket are assembled. The gussets and, in the case of a suspended bike, the shock mount and shock lever pivot, will be welded after the first aligning step of the frame.

As the welding process involves heat deformation of the alloy, it is important for reducing those deformations that the welder welds the different junctions in a precise order. This order has been determined empirically by the welder to balance the heat deformation on the frame and is represented in the Figure 33.

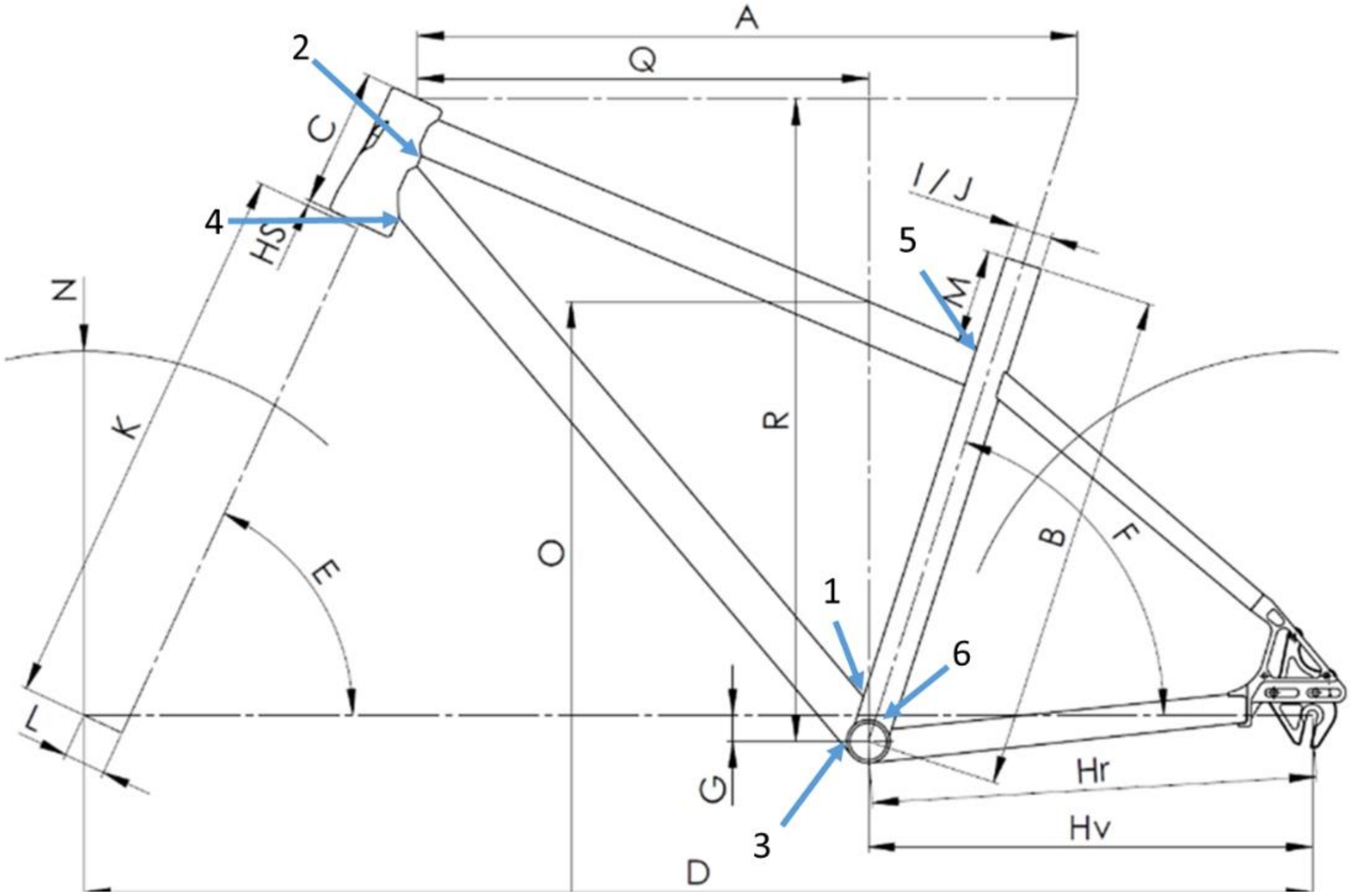


Figure 33: Tacking order of a Nicolai hardtail frame

3.2.5 Reaming of Head tube and Bottom Bracket.

In order to align the front triangle on the aligning jig, it is necessary to ensure that the interfaces of the frame and the jig fits together. Indeed, during the welding, the head tube and the bottom bracket are slightly deformed and both cylinders cannot fit on the aligning jig interfaces. Therefore, it is necessary to ream the head tube and the bottom bracket before the aligning step.

3.2.6 Aligning front triangle.

The alignment process is an important step of the frame production. It corrects all the deformation due to the welding process and ensure that the steering axis, the seat tube axis and the rear wheel are all in the same plane that forms the center of the bike. The alignment is carried out several times throughout the production because the final deformations would be too important to carry the alignment only once at the last process. In this case, the front triangle is aligned to be used later as a reference for the positioning of the rear triangle. The alignment process is carried out in three steps:

- Perpendicularity of the seat tube to the bottom bracket axis.

This step will create the first reference for the aligning of the head tube. The bottom bracket is used as primary reference (see Figure 34) and the perpendicularity between the bottom bracket axis and seat tube is checked and corrected if necessary. To do so, the operator place the frame on a special bottom bracket mount and check the deviation of the seat tube on its length. The deviation is reduced by placing a metal rod in the seat tube and plastically deforming the tube.

Figure 34: Checking of seat tube perpendicularity regarding bottom bracket axis

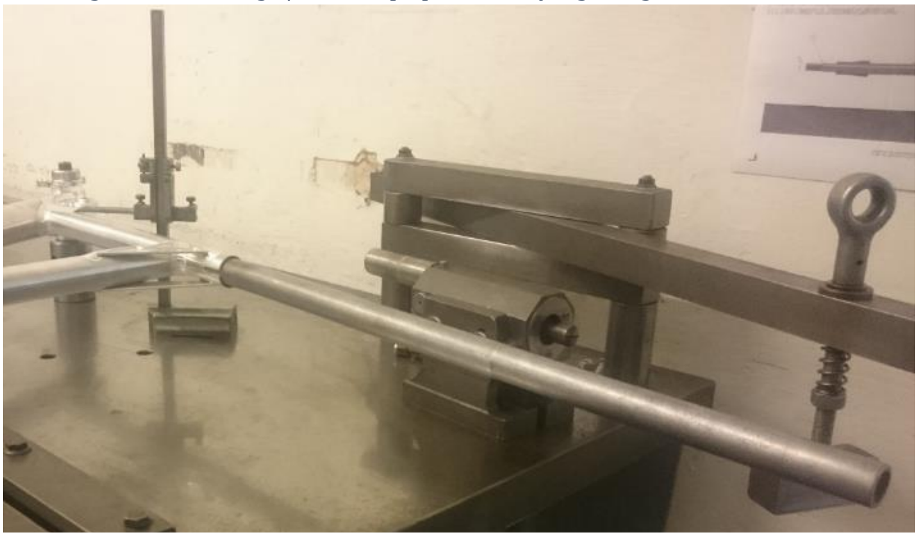


Figure 35: Metal rod used as a lever placed in seat tube to deform it

- Co-planarity of the head tube to the seat tube.

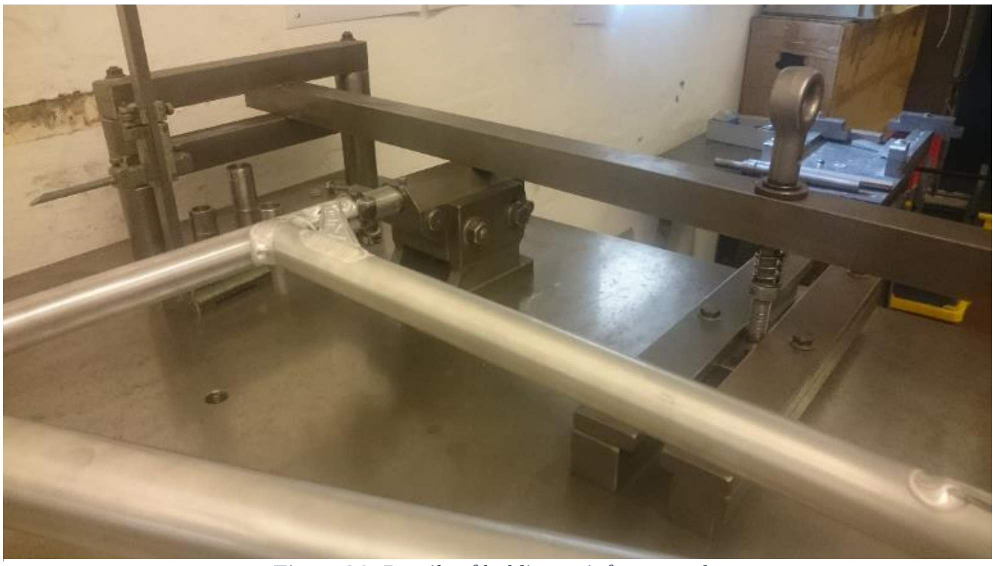


Figure 36: Details of holding unit for seat tube

This step will verify the co-planarity between the seat tube and the head tube. The primary reference used is still the bottom bracket axis and the second is the seat tube. To transform the seat tube as a reference for the aligning, a gauge is placed in the seat tube that fix its axis relatively to the marble panel and the bottom bracket axis (see Figure 36)

The aligning device of the head tube consists of two cups placed at each end of the head tube and a metal rod through them. The deviation of the head tube axis will be checked via observation of the distance between metal rod and a reference gauge at two different points: one close to the head tube and one at the end of the metal rod (see Figure 37). Once a deviation is observed, the metal rod will be inserted at one of its ends into a ball and socket joint (see Figure 38) and used for plastically deforming the head tube by forcing upward or downward on the metal rod extremity. The process of checking co-planarity and deforming is repeated until the vertical deviation is under 1mm between the bottom of the head tube and at 500mm from the head tube on the metal rode.

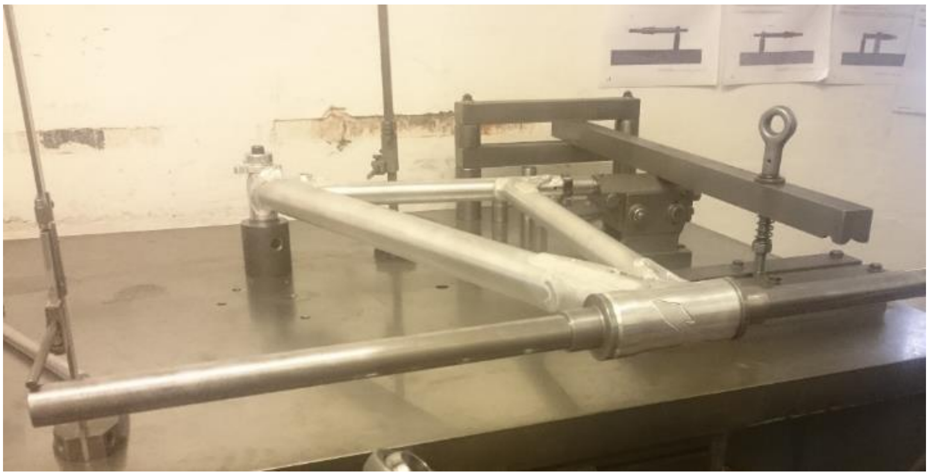


Figure 37: Checking of co-planarity of head tube axis and seat tube axis.

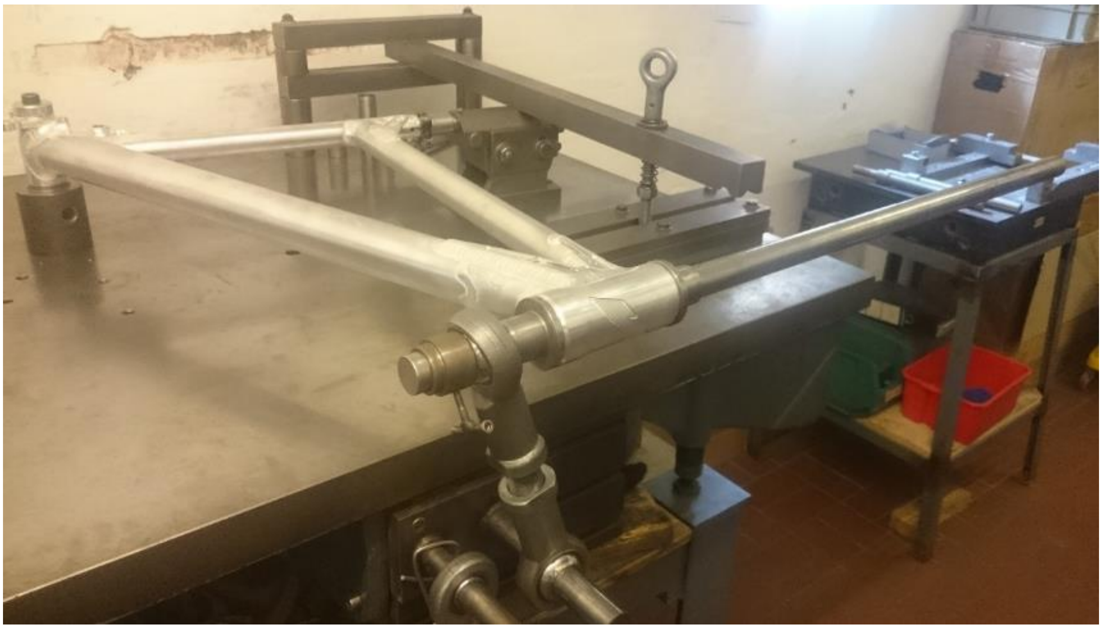


Figure 38: Details of ball socket system that holds the metal rod

- Aligning of the head tube on center plane of the frame.

This aligning step guaranties that the steering axis is coincident with the center plane of the frame. To do so the lower head tube hole is fit around a special gauge (see Figure 39) that uses the marble plate as reference. If the gauge does not fit inside the head tube, the head tube is deformed vertically. This process of checking and deforming is repeated until the gauge fits freely inside the lower head tube hole (see Figure 40)

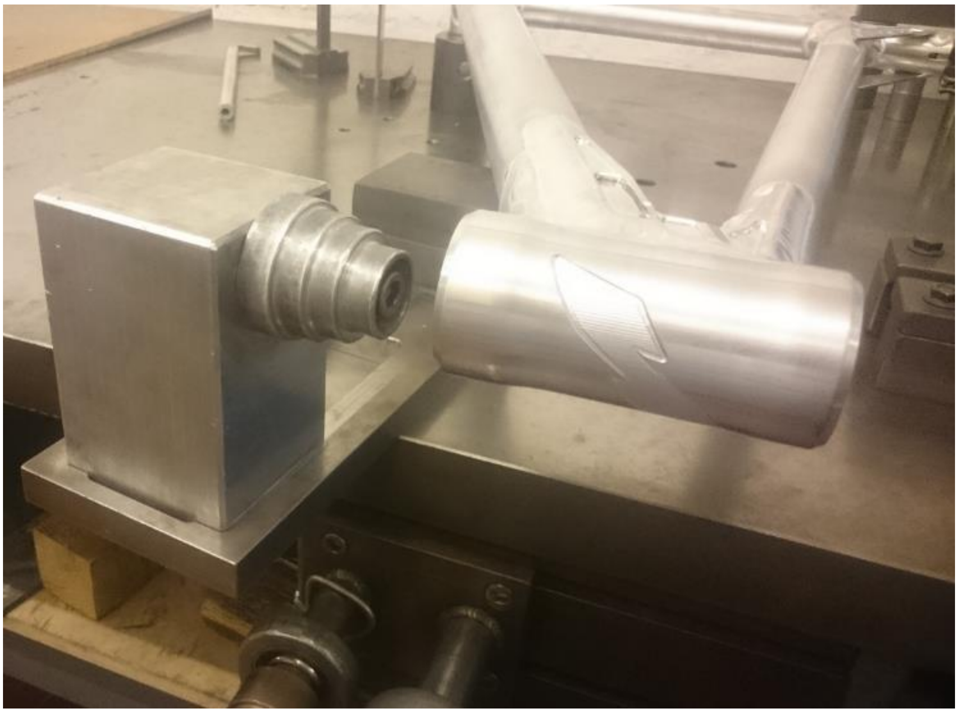


Figure 39: Special gauge used for locating of head tube axis

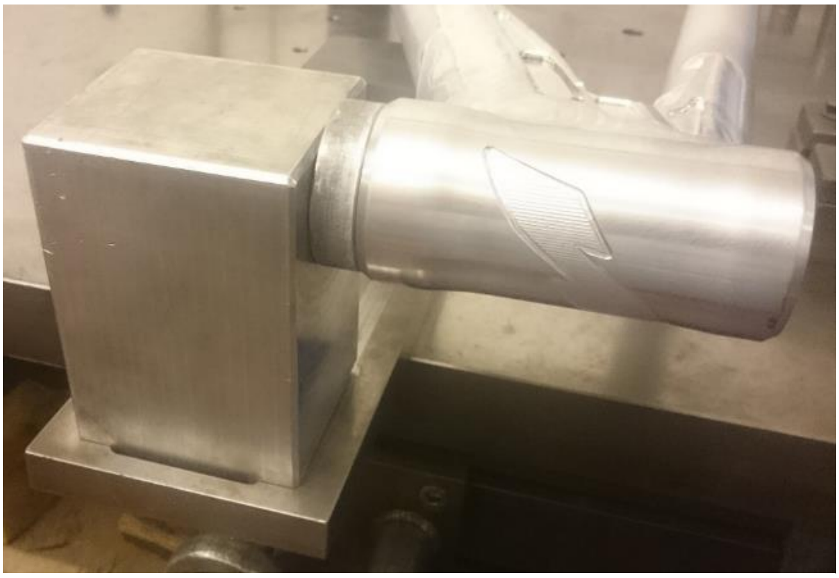


Figure 40: Special gauge fitting into head tube.

3.2.7 Welding gussets on front triangle.

Once the front triangle has been aligned, the gussets are welded at the head tube junction with the top tube and down tube (see Figure 41). This process comes after the aligning of the frame in order to facilitate the aligning process for the operator, indeed the gussets would rigidify the frame and require a higher load to deform the frame.

Figure 41: Gussets welded on front triangle of a Nicolai frame

The welder places the gussets by hand on the frame. On a suspended bike, this step also includes the tacking and welding of the shock mount and the shock lever pivot. Those two machined part on the Figure 42 and Figure 43 are positioned in two steps:

- Welding of the shock lever pivot.

The shock lever pivot position is located along the down tube using a custom jig that has for reference the chain stays pivot (see Figure 42).

Figure 42: Locating device for shock lever pivot

- Welding of the shock mount.

The shock mount position is located along the down tube using a custom jig that has the shock lever pivot for reference (see Figure 43)

Figure 43: Locating device for shock mount

3.2.8 Positioning the rear triangle on the welding jig.

The front triangle is now finished and set the reference for the positioning of the rear triangle. As described in Figure 44, the rear triangle is made of four different entities:

- The yoke and seat stays
- The hoof and chain stays
- The drop outs
- The seat tube.

In order to position those four entities according to the frame geometry, they are placed in a jig for being tacked. However, the rear triangle jig can be used for different sizes of frames within the same model design. Indeed, as described in the literature review 2.2, the difference between two sizes of bicycle frames concerns the reach, the stack and the stand over. Therefore, the chain stays length does not change and the seat stays rotate around the upper part of the drop outs to be aligned with the top tube.

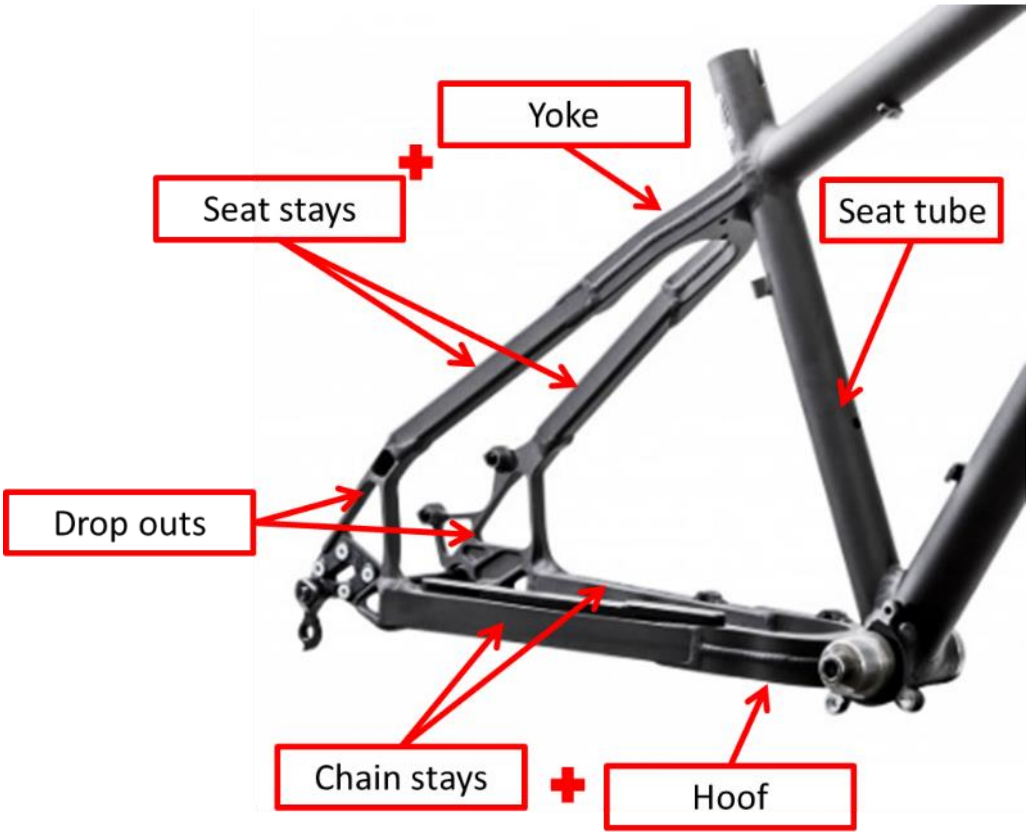


Figure 44: Different groups composing the rear triangle of a hardtail bicycle frame

The yoke and the hoof are mitered in order to fit properly around the seat tube and bottom bracket (see Figure 45).

Figure 45: Mitered yoke of a hardtail Nicolai frame

Once the tubes are positioned and fixed in the jig (see Figure 46), the welder tacks all the different part together.

Figure 46: Fully assembled hardtail Nicolai frame ready for final tacking

3.2.9 Welding of chain stays, seat stays, drop out, hoof and yokes together without front triangle.

The complete frame is then removed from the rear triangle jig and the welder welds the drop outs to the seat stays and chain stays. Finally, the chain stays and seat stays are welded respectively to the hoof and the yoke (see Figure 47). However, the hoof and yoke are not welded yet to the seat tube in order to facilitate the aligning of the rear triangle to the front triangle.

Figure 47: Nicolai frame fully tacked

3.2.10 Aligning rear triangle to front triangle

The alignment of the rear triangle to the front triangle is made by the technician in charge of the assembly. The frame is placed in the aligning jig via the bottom bracket, see Figure 48. This jig uses different template cylinders to ensure that the drop outs are centered on the centerline of the bike. The technician deforms each side on the rear triangle until the template cylinder that correspond to the good axle size fits (see Figure 50). Once the alignment is done, the axle length is controlled using a caliper and the tire clearance is checked using a special device (see Figure 49).

Figure 48: Frame located by bottom bracket on the rear triangle aligning jig

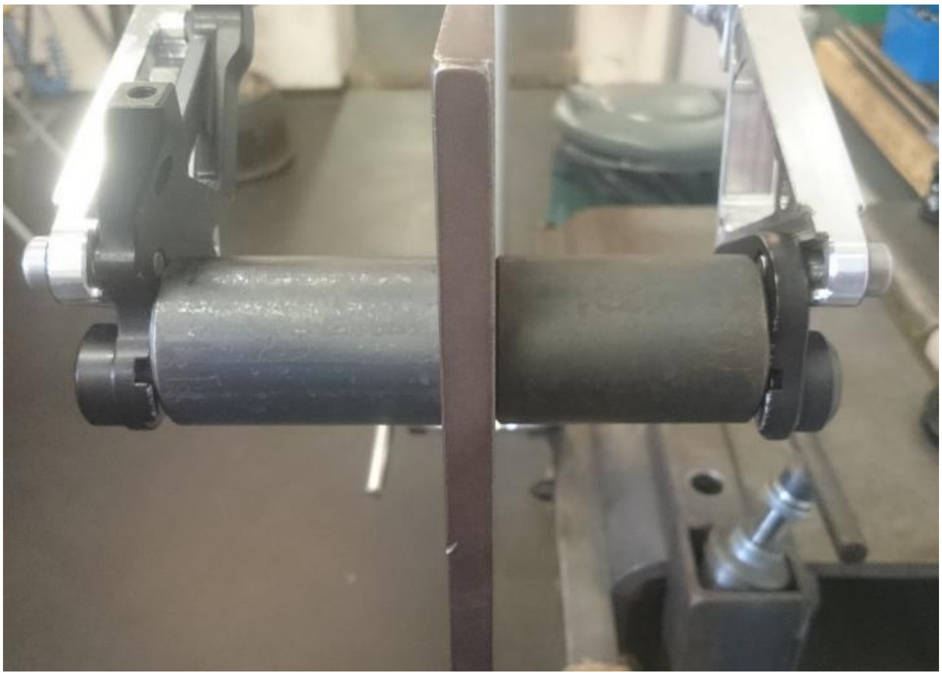


Figure 50: Template cylinders for ensuring compatibility with rear axle standard dimensions

Figure 49:Tool for control of the tire clearance

3.2.11 Welding front triangle to rear triangle

Once the rear triangle is aligned to the front triangle, the hoof and yoke are welded to the front triangle (see Figure 51). The welding process is now finished.

Figure 51: TIG Welding of the yoke to the seat tube

3.2.12 Aligning full frame

The complete assembly of the tubes is now finished; the frame is aligned once more before the heat treatment. The process is identical to the step 6 and 10.

3.2.13 Heat treatment

The frame is then following an annealing after welding to remove all the internal stress. The oven is heated to 100°C during 10 hours and then 140°C during 4 hours.

3.2.14 Machining seat tube and cable holders

As the welding processes are finished, the interfaces frame/components are not anymore subject to thermal deformation. Therefore, the finishing machining steps can be carried out. However, some operations need to be done before the painting or anodizing process and some operations can be done afterwards.

The reaming of the seat tube is done before painting because the important length of the reaming tool and the cutting forces may damage and crack the layers of powder coating. The seat tube is reamed to the final dimension of 30.9mm or 31.6mm according to the seat post standards.

For the same reasons, the holes for the cable holders or water evacuation are carried out before painting. (see Figure 52)

Figure 52: Threaded holes for cable holders on a Nicolai frame

3.2.15 Painting or anodizing

The frame is then cleaned with dish soap and steel wool. Depending on the choice from the customer, the frame can be painted or anodized. The powder coating process is executed at Nicolai GmBH while the anodizing is outsourced.

If the frame has to be anodized, an operator sand-blasts the frame at Nicolai GmBH and then sends it to the company Kothe Galvanic for anodizing.

If the frame requires powder coating, the operator first protects the bottom bracket threads, cable holder holes and disc brake mounts with plugs and then applies a first layer of powder on the frame (see Figure 53). The frame is then placed in an oven at 120°C during 25 minutes for the powder coating to melt and solidify. After cooling down to room temperature, a second and final layer is applied and the heating process is repeated.

Figure 53: Powder coating of a Nicolai frame

3.2.16 Machining Bottom Bracket, Head tube, shock mounts and pivot

Finally, the last machining steps are conducted:

- The ISCG 05 interfaces for chain guides are face milled to guarantee their flatness (see Figure 54).
- The head tube upper and lower holes are reamed to their final dimension in order to meet the standard dimensions of the headset.
- The Bottom bracket unit is face milled in order to meet the bottom bracket dimensions' standards (68,73,83 or 100 mm) and the threads are machined once more by hand to ensure the proper fit of the bottom bracket cups.
- On a suspended bike, the pivots and shock mounts are milled to ensure the good fit of the chain stays or shock lever.

Figure 54: ISCG 05 interface milled on a Nicolai frame

3.2.17 Aligning

The frame is finally aligned one last time following the step six and ten in order to guarantee a perfect alignment of the tubes. Moreover, the alignment of the rear wheel is now corrected using a Nicolai particular system that consists of a derailleur hanger with angle offset.

The employee responsible for the assembly and the alignment can select between rear derailleur hanger with an offset of -2, -1,0,1 or 2 degrees of camber (see Figure 55). This rear derailleur hanger will allow to correct the camber deformation of the wheel without adding too much stress on the rear triangle as if plastic deformation were carried out.

Figure 55: Description of camber misalignment

The alignment is controlled using a reference rim perfectly straight and a long metal bar with comparator. (see Figure 56)

Figure 56: Aligning the rear wheel on the head tube
Source: http://www.nicolai-bicycles.com/

3.2.18 Assembling

The assembly process is really different between a hardtail frame and a suspended frame. Indeed, the suspended frame will require much more time for the assembling of the bearing, axles and seals in each pivot of the suspension design. As we focused on the building of a hardtail frame we will simply detail this process.

The assembly of a hardtail frame only consists in placing the cable holders and the rear axle in the frame. (see Figure 57)

Figure 57: Cable holder on a Nicolai frame
Source: http://www.nicolai-bicycles.com/

Before going into the packaging step, the frame is controlled one more time regarding the specification of the customer: Color of frame and color of cable holders, size, model. A quality form is then filled (see Appendix 7: Quality form for the assembly of each Nicolai frame.) and the frame is photographed to be kept in the database of the company.

3.2.19 Packaging

The frame is then wrapped up in plastic foil and protective foam and placed in a box. An extra derailleur hanger is shipped to the customer in case of breakage.

3.2.20 Shipping

The bike is shipped to a Nicolai GmbH Dealer or directly to the customer.

3.3 Analysis of Current tailor made jig at Nicolai GmBH

The current welding jig presented in the Figure 58 does not satisfy the actual needs of Nicolai GmBH.

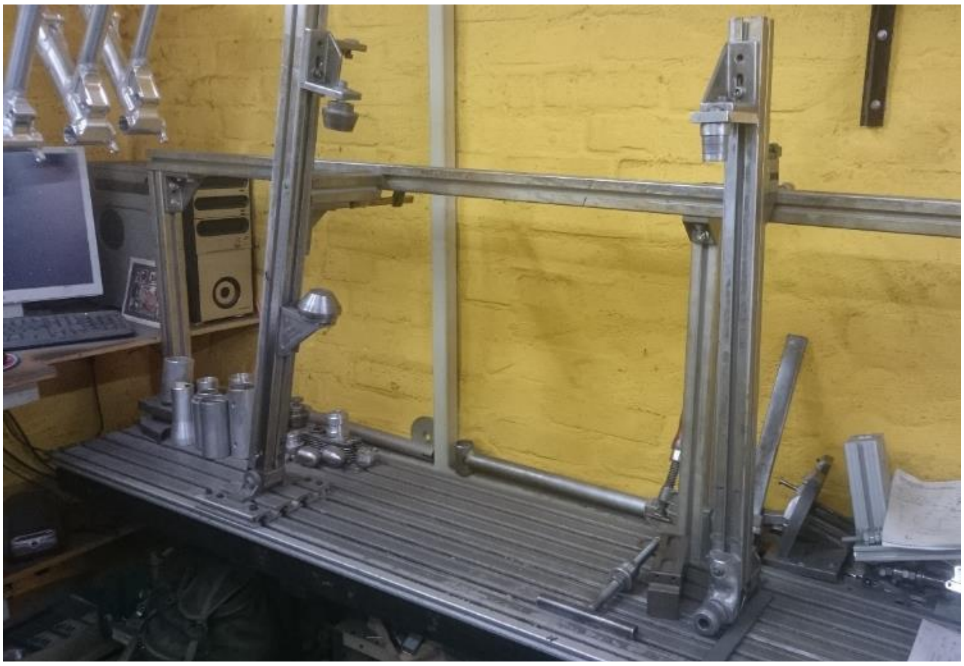


Figure 58: Current welding-jig for tailor-made frame

The design of this welding jig does not represent the actual geometrical parameters of a frame and therefore requires special setting parameters. As we can see in the Figure 58, the fork rake and bottom bracket height are not displayed on the jig and the pivot does not coincide with the front wheel axle. This forces the engineer to define the position of the head tube with only three parameters represented in red in the Figure 59 instead of five in the real geometry:

- The bottom bracket height
- The fork length
- The fork rake
- The head angle
- The reach

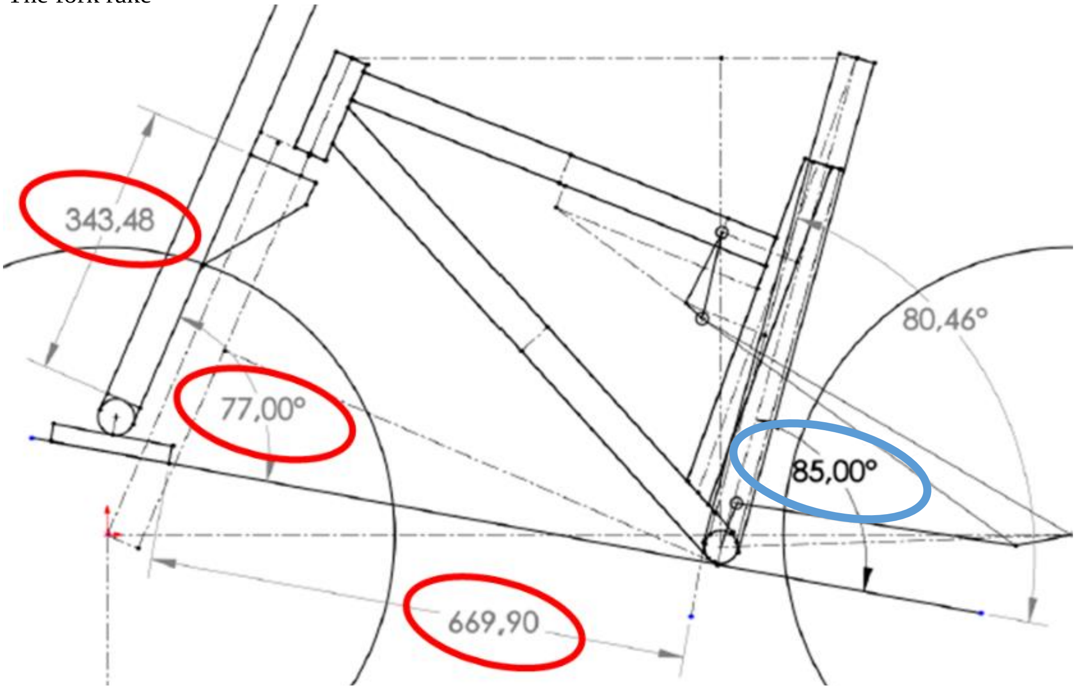


Figure 59: Setting parameters for the current welding-jig for tailor-made frame

In a case of a suspended frame, an angle offset of the seat tube is required to avoid collision between the seat tube and the rear wheel when going through the travel of the suspension (see Figure 60).

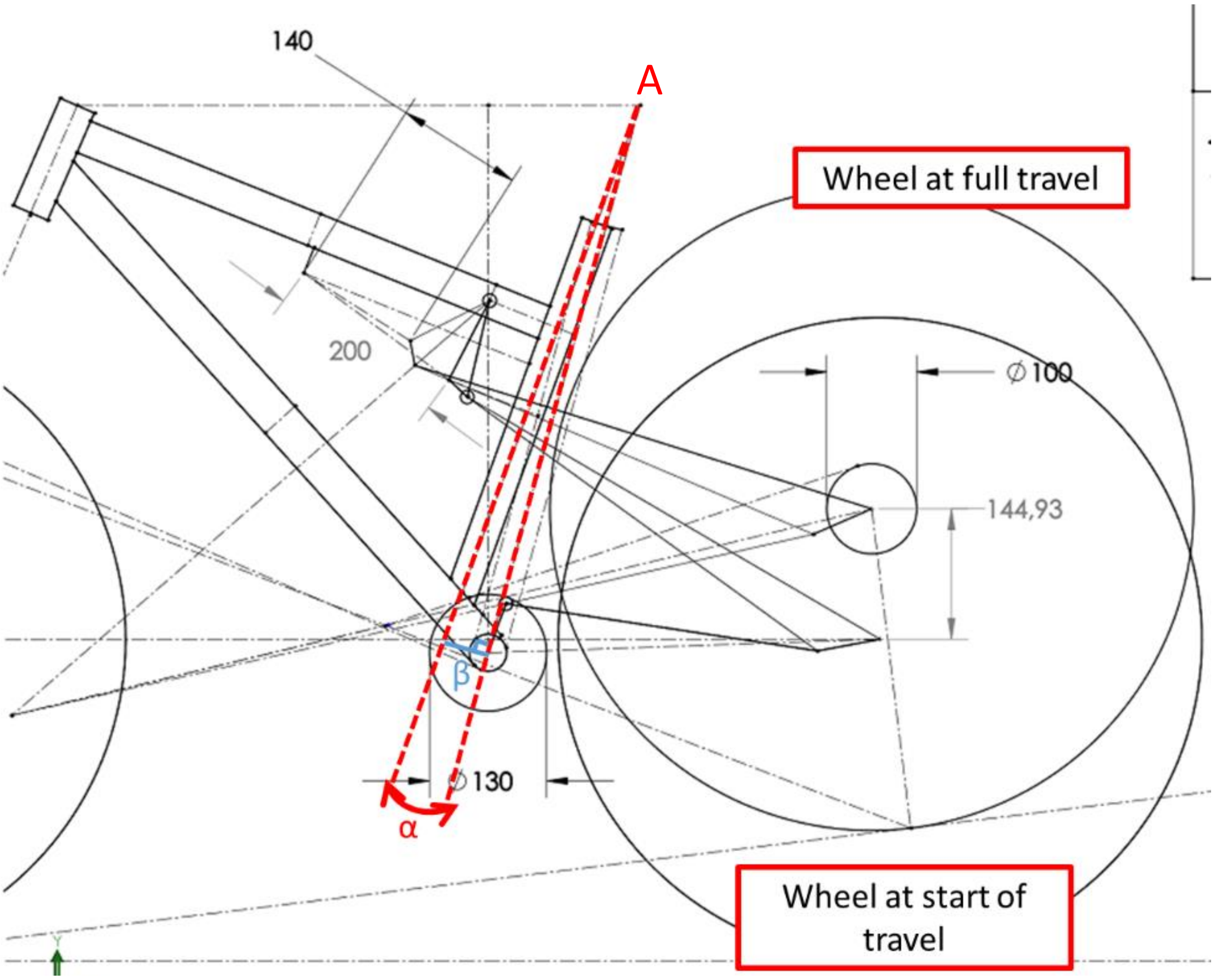


Figure 60: Explanation of need for an offset angle on the seat tube in the case of a suspended frame

The current jig does not allow any rotation of the seat tube around its highest point (marked as A in the Figure 60). Thus requiring again, a different setting parameter than the real geometrical parameter in order to define the position of the seat tube. This specific parameter (marked as blue in the Figure 60) require once more to use the drawing provided by the engineer at the Figure 59.

Furthermore, the current welding jig does not provide any support for the top and down tube while tacking. Those tubes are held by the welder or compressed enough by the angles of the geometry to not fall. These requires some attention from the welder that could be avoided.

Finally, the welding jig being located in the welding jig workshop and not movable, it requires the technician in charge of cutting the tube to move back and forth between his station and the jig. This leads to useless motion waste and can disrupt the welder.

4 Project development

Nicolai GmBH is a small company specialized in the manufacturing of high quality and performances mountain bike. One of its main marketing approach is the label "made in Germany". This company tries to provide a customizable service to the customer who can choose between standard sizes or tailor-made geometry. Currently, the tailor-made geometry manufacturing process is avoided as much as possible because too time-consuming and Nicolai GmBH has to refuse orders for tailor-made geometries or advise the customer towards a standard size.
Firstly, as described in the previous chapter, the current process of building tailor made geometries is slowing down the welding process that is already the current bottle neck of the production. Moreover, for the engineer in charge of tailor-made geometries, the design of a new geometry is decided after a mail exchange with the customer. This exchange can be very long as the engineer has sometimes to guide entirely the customer in his choices or convince him of some modifications regarding his initial request.
Karlheinz Nicolai decided to design a new welding jig for tailor-made bicycle frames that would answer those problems by simplifying the setting of the geometry, make modifications easier and therefore allow more tailor-made bikes to be manufactured. Moreover, Mr. Nicolai decided that the welding jig to be designed will be also used in the standard production of the new 2017 model of hardtail frame, the argon GLF.
In this part of the study, we will follow step by step the design and the manufacturing of this welding jig. To begin, we will analyze the requirements expressed by Mr. Nicolai, then define the range of settings of the welding jig. Afterwards, we will go through the design process by following the development of a kinematic design and the conception of each components of the jig. To finish, we will describe the manufacturing of the jig, its calibration and finally the welding of a frame on it.

4.1 Requirements for welding jig

Firstly, the welding jig to be designed has for purpose to position the frame elements relatively to each other following a certain geometry and to maintain this geometry only during the tacking. The complete welding of the frame will be carried out outside of the jig. This specification allows for the welder to move the frame as desired more easily for a better access while welding and also free the jig more quickly for a subsequent use.
One of the main requirements from Mr. Nicolai was that the new welding jig needed to show every geometrical parameter of a bicycle frame. Indeed, the current tailor-made jig design does not represent the geometrical parameters of a mountain-bike (see 2.2). Therefore, the engineer in charge of the geometry definition needs to convert the real frame geometrical parameters when setting parameters for the jig. This process is not efficient and does not allow for easy modifications of the geometry because one setting parameter of the jig can influence several real frame geometrical parameters.
The welding jig must be capable of allowing geometries ranging from a small BMX frame to an extra-large downhill bike. Indeed, Nicolai GmBH produces every type of bicycle and must be able to build extreme geometries for special orders such as the manufacturing of a BMX frame for David Graf, Swiss rider competing in the Rio Olympic games in 2016 or a downhill bike frame for a two-meter-tall rider.

On another hand, the new welding-jig has to be able to hold in position a complete hardtail frame. This requirement aims at reducing the number of alignment operations during the manufacturing of a frame. Indeed, the mechanic in charge of the assembly needs to interrupt his current task to carry out the alignment of the frames in order to make them available for the next welding step. By positioning the complete frame in one step in the jig, the alignment steps could be reduced to the alignment before heat treatment and alignment before assembling. (see Table 2)

Current Aligning steps	Aligning steps with new welding jig
Aligning of Front Triangle	X
Aligning of Rear Triangle	X
Aligning of Front Triangle and Rear Triangle before heat treatment	Aligning of Front Triangle and Rear Triangle before heat treatment
Aligning of Front Triangle and Rear Triangle before assembly	Aligning of Front Triangle and Rear Triangle before assembly

Table 2: Description of aligning steps of the frame to be carried with the current welding-jig and with the future welding-jig

Additionally, the welding jig must be easy to use for the welder and the technician in charge of cutting the tubes. Consequently, it has to be easy to set and easy to move around the production facilities. This contrasts the current welding jig which is fixed in the welding workshop and does provide only one direction of access for the welder. Finally, regarding the manufacturing of the jig, the use of standard parts available on the market has to be maximized. The machines and technicians at Nicolai GmBH being occupied full-time for the production of bicycle frames, it is then preferable to minimize the additional workload on them. To do so, it has been strongly suggested by Mr. Nicolai to design the welding jig using extruded aluminum profile type Bosch Rexroth (see Figure 61).

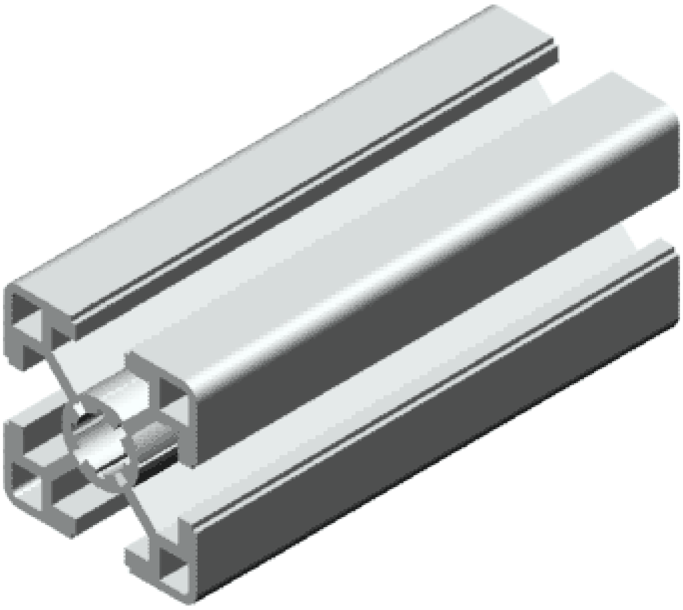


Figure 61: Representation of a CAD model of a Bosch Rexroth profile
Source: www.boschrexroth.com

4.2 Definition of the range of modulation

A bicycle frame geometrical parameters could take theoretically any finite value. But, as the frame is only one component of the complete bike, it has to be compatible with other components that makes the bicycles: wheels, fork, bottom bracket, saddle, etc. One solution would be that every bicycle manufacturer design every components of the complete bike in order to choose and control the interfaces between each components similarly to the aeronautics or automobile industry. In the high end bicycle industry, the components found on a bike comes mainly from different manufacturers. Therefore, in order to organize and simplify the compatibility between components and facilitate the second-hand market, standards have been created within the bike industry. Those standards reduce the range of variation of some parameters to several precise and defined values.

On another hand, in order to reduce the number of customized parts to produce for a tailor-made frame, Nicolai GmBH does not provide the customer an infinite range of choices regarding machined components on the frame such as head tube or drop outs.

In this section we will describe the creation of an internet form aiming at guiding the customer through the options available in the building of his tailor made geometry. Additionally, we will go through the industry standards selected by Nicolai GmBH for the customization of a tailor-made frame and the limited variance imposed by the company regarding the machined parts. Finally, we will define the range of customization required for the parameters that does follow any standard or Nicolai GmBH restrictions.

4.2.1 Development of a customer form for tailor-made order

The reception of a tailor-made order from a customer starts a procedure of mail exchange with the engineer in order to define the geometry according to the will of the customer, the standards of the industry and the range of modulation offered by Nicolai GmBH. Because this exchange of mail increase the workload on the engineer, a customer form has been created in order to inform the customer on the variances available and to collect his will regarding the design of the geometry.

This customer form is directed to customers who have a precise will regarding their geometry. However, most of the customers requesting tailor-made geometry are riders who need advice and therefore the mail exchange with the engineer cannot be avoided.

This customer form available in the Appendix 8: Internet customer form, has been developed using the free Google form platform and is divided in several sections as following:

- Personal information:

In this section, the customer fills in his personal data such as name or contact for further discussion concerning the geometry or order.

- Base model selection:

In this section the customer selects the base design of the frame and the wheel size of the bike. The choice is reduced to the three designs offered by Nicolai:

  - Argon: rigid frame
  - Helius: Suspended bike with shock mount on the top tube following a Horst link suspension

design. The Helius design is used in the Nicolai range for cross-country or trail riding (see Appendix 1: Description of the different mountain bike disciplines.).

- Ion: Suspended bike with shock mount on the down tube following a Horst link suspension design. The Ion design is used in the Nicolai range for aggressive riding such as enduro or downhill riding. (see Appendix 1: Description of the different mountain bike disciplines.)

- Rear suspension travel:

In the case of a suspended design such as Helius or Ion, the customer can choose between several values of travel for the suspension. (see Table 5 presented in the next section)

- Geometrical information:

In this section, the customer informs the engineer on the geometry requested. When the choice in the configuration is restricted by some standard or by the company, a table is displayed to guide the customer through his choice. The tables displayed in the form are Table 5, Table 6 and Table 7 that will be presented in the next section.

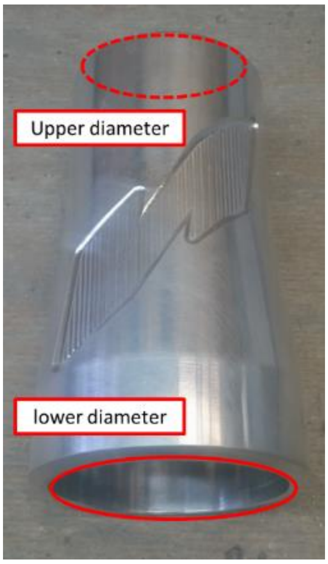
- Additional configuration:

In this section, the customer can select different options such as the position of the cable holders or the number of bottle cage holder.

Finally, the customer is informed that his/her request has been registered by Nicolai and that the engineer in charge will contact him/her as soon as available.

4.2.2 Variance restrictions from bicycle industry standards and Nicolai GmBH.

The bicycle industry is composed of dozens of frame manufacturers and components manufacturers. It is consequently necessary to regulate and standardize the dimensions of each component for their compatibility. As there is no regulation office for those standards, small manufacturers of frame or components have to follow the standard defined by bigger brands. Nicolai GmBH follows then the most common standards in the mountain bike industry. Those standards' dimensions and the geometrical parameters associated are presented in Table 3.

Parameters	description	illustration	Standards adopted by Nicolai GmBH
Wheel size	Outer diameter of the wheel		27,5 inches 29 inches 700C
Head tube upper and lower inner diameter	Interface between head tube and headset (bearings ensuring the steering movement)		<u>Configuration 1:</u> Upper diameter ZS44 + Lower diameter ZS56 <u>Configuration 2:</u> Upper and lower diameter EC49 (See Appendix 9: Head tube standard)
Seat tube inner diameter	Interface between frame and seat post		31.6 mm 30.9 mm

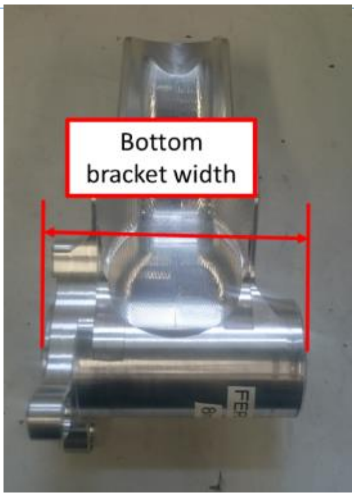
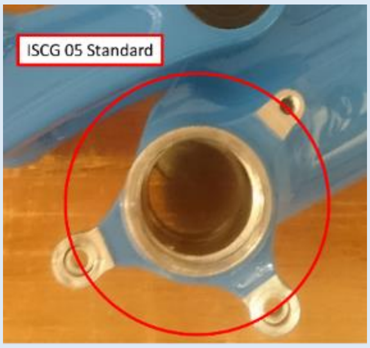
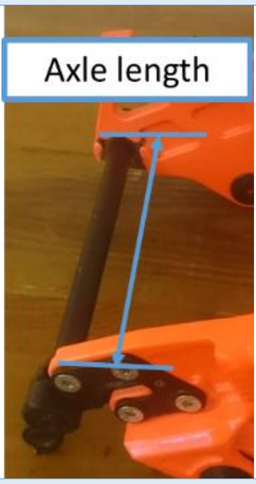
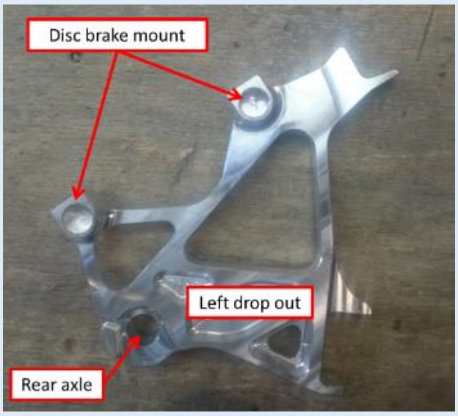
Width of bottom bracket unit	Interface between frame and bottom bracket bearings (bearings ensuring rotation of cranks)		68 mm 73mm 83mm 100mm
Chain guide mount standards	Interface between frame and chain guide (ensuring that the chain stays in the chain ring when vibrations)		ISCG05 (see Appendix 10: ISCG standard)
Rear axle dimension standards	Interface between the frame and rear wheel		<u>Length x diameter</u> 135x 10mm 142x12mm 148x12mm 157x12mm 170x10mm 177x12mm
Brake mounts standards	Interface between frame and disc brake mount		Type + diameter disc PostMount 160mm PostMount 180mm IS2000 160mm (see Appendix 11: Brake mount standard)

Table 3: Description of the bicycle industry's standards adopted by Nicolai GmBH

Now that we have been through the industry standards followed by the company, we will study the variances available within the frame components. Indeed, as described in the introduction of this section, Nicolai GmBH limits the number of variance available regarding the machined parts that compose the frame. By doing so, Nicolai GmBH focuses the building of a tailor-made geometry only on the relative position of each of the components of the frame and not the design of new components. Thus allowing them to reduce the cost of tailor-made production and their lead time.

In Table 4, a summary of the limitations of variance imposed by Nicolai is proposed. We can see that the chain stay for the suspended bike is limited to a minimum in order to prevent the rear wheel to collide the seat tube when going through the travel of the rear suspension.

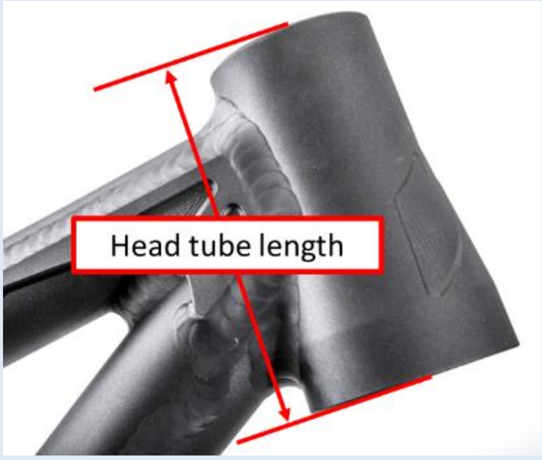
Parameters	Description	Illustration	Limitation of variance
Head tube length	Distance between top and bottom of head tube		110mm 120mm 130mm 150mm
Chain stay length	Horizontal distance between bottom bracket and rear axle		<u>On Hardtail:</u> Minimum imposed by the diameter of the wheel selected in order to avoid collision between rear wheel and seat tube <u>On suspended bike:</u> Minimum 435mm or 445 mm depending on the suspension design selected

Table 4: Description of variances limitation imposed by Nicolai GmBH

Nicolai GmBH provides three different types of frames: one hardtail geometry, the Argon, and two suspended geometries, the Helius and the Ion. By their different designs, those three geometries are not intended for the same use. Therefore, not all the three geometries can accept all the standard followed by Nicolai because those standards depend on the use of the bicycle. For example, an Ion geometry is designed mainly for aggressive riding and will not accept a bottom bracket 68mm wide that corresponds to road bike components. In order to clarify the combinations available in the Nicolai range of geometry design and standards, a summary is presented in the Table 5 and Table 6.

Geometry	Wheel size	Suspension travel (mm)
Helius	27,5"	140
	29"	120
Ion	27,5"	160
		155
	29"	145
Argon	27,5"	0
	29"	0

Table 5: Combination of geometry design, wheel size and suspension travel available at Nicolai GmBH

The Table 5 represents the combination between the geometry chosen, the wheel size standard and the travel available for the rear suspension.

	Rear axle dimensions availables and Brake Mount standards associated with it		
	Rear axle dimensions		
	142x12mm		
Ion 15	PM 180		
Ion 16			
Ion GPI			
Ion Geometron			
Helius TB			
Helius AC			
	Rear axle dimensions		
	157x12mm		
Ion 20	PM180		
	Rear axle dimensions		
	135x10mm	142x12mm adjustable	142x12mm fixed
Argon AM		PM180	PM160
Argon AM-PI			
Argon TB			
Argon TB-PI			
Argon TR	IS2000-160		
Argon TR-PI			
	Rear axle dimensions		
	135x10mm adjustable	135x10mm fixed	
Argon CX	PM160	IS2000-160	
	Rear axle dimensions		
	170x10mm	177x12mm	
Argon FAT	IS2000-160	PM180	
Argon FAT-PI			

Table 6: Description of rear axle dimensions and disc brake mounts available regarding the geometry selected

The Table 6 shows the actual combination found in the Nicolai GmBH 2016 range regarding the geometry chosen and the rear axle dimensions available for this geometry. The brake mount standard follows according to the two previous options. On another hand, the Table 7 presents the minimum length for the chain stays according to the design chosen.

Geometry	Use	Wheelsize	Minimum chainstay length
Argon	MTB	27,5"	425
		29"	435
	Road	700C	405
Helius/ion	MTB	27,5"	435
		29"	445

Table 7: Minimum chain stay length available according to wheel size and geometry design selected

By this analysis of the standards followed by Nicolai, presented in the Table 3, and the limitation of variances imposed by the company, presented in the Table 4 and Table 6, we can determine the parameters that will be able to take any values during the definition of the geometry:

- Head angle
- Fork Length
- Fork rake
- Bottom bracket height
- Seat tube angle
- Seat tube length
- Seat tube offset
- Reach
- Stack
- Top tube length
- Wheel base
- Stand over

Those parameters have already been presented in the literature review concerning geometry, however, for a clear understanding, they are presented once more in the Figure 62 and Table 8.

In the next section, we will define the range of variation of those parameters by inspecting the geometries of a BMX frame and a Downhill mountain bike as requested by Mr. Nicolai.

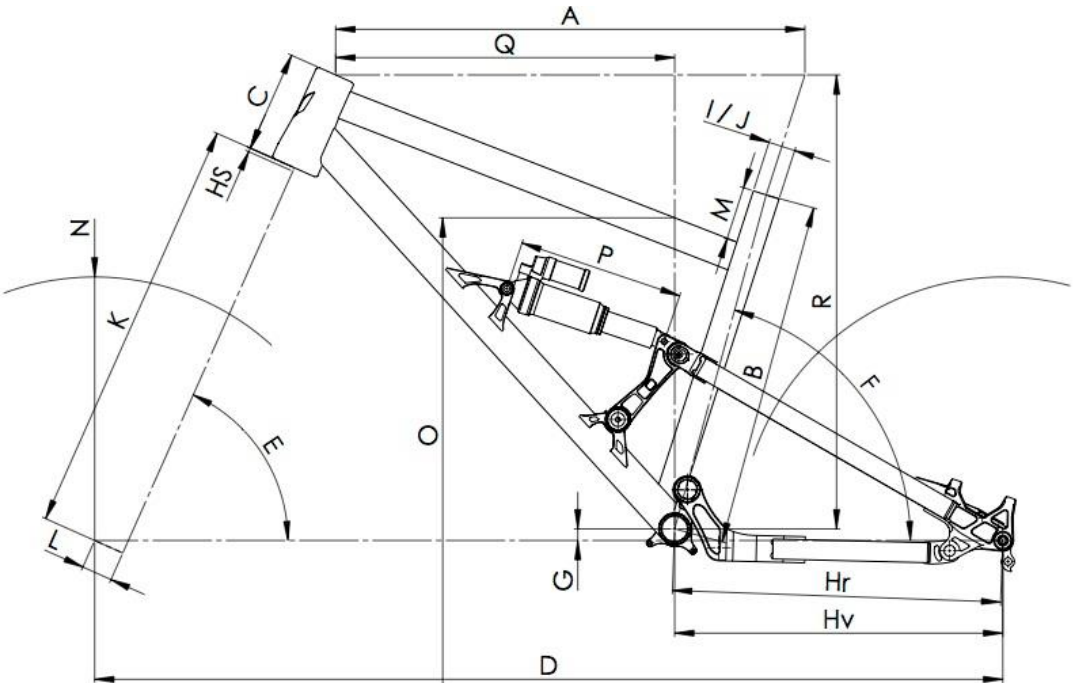


Figure 62: Geometrical parameters of a bicycle frame

	Geometry parameters	Additional description
A	Top tube length	Virtual horizontal distance between the top of the Head tube and the seat tube
B	Seat tube length	Distance between bottom bracket and top of seat tube
C	Head tube length	
D	Wheel base	Horizontal distance between the axles of the front and rear wheels
M	Seat tube offset	Distance between the top of the seat tube and the top of the top-tube at their intersection
O	Standover	Distance between the ground and the top of the top tube on a vertical line passing by the bottom braket
Q	Reach	Horizontal distance between bottom bracket and top of the head tube
R	Stack	Vertical distance between bottom bracket and top of the head tube
E	Head angle	Angle between the head tube and the ground
F	Seat angle	Angle between the seat tube and the ground
G	Bottom bracket drop	Vertical distance between the bottom bracket and the axles of the front and rear wheels
Hr	Chain stay length	Distance between bottom bracket and rear axle along a line joining the two point
Hv	Effective chain stay length	Horizontal distance between bottom bracket and rear axle
I	Seatpost diameter	
K	Fork length	Distance between the bottom of the head tube and the front axle along the axle of the head tube
L	Fork rake	Distance between the bottom of the head tube and the front axle along a right line of the head tube axle
N	Tyre diameter	
P	Shock absorber length	Distance between shock mount eye and shock lever eye

Table 8: Description of the geometrical parameters of a bicycle frame

4.2.3 Range of modulation of geometrical parameters

The range of modulation proposed by the Anvil Bikeworks Type 4 presented in the 2.4.1 can provide a first draft for our own welding-jig. Nevertheless, we will base our design on its capability of building bicycle frame from a small BMX to an extra-large downhill bike.

The two models that have been chosen for this analysis are the Nicolai Ro20 used by David Graf and the Nicolai Ion G19 in extra-large. The comparison of the two models is made in the Table 9.

Geometry parameters	Nicolai Ro20 small	Nicolai G19 XL
Top tube length	590	661
Seat tube length	250	490
Head tube length	130	130
Wheel base	1007	1313
Seat tube offset	40	70
Stand over	498	780
Reach	452	520
Stack	399	615
Head angle	74	61
Seat angle	71	77
Bottom bracket drop	+27.5	-17
Effective chain stay length	400	450

Table 9: Comparison of geometries on the Nicolai R020 and Nicolai G19 frames

This analysis confirms the range proposed by Anvil Bikeworks on the type 4 model. To ensure that the welding jig could produce any geometry, the range of variation has been extended.

The base for the fork length and fork rake range of modulation have been selected following the dimensions of a small BMX fork and a downhill fork available at Nicolai GmBH.

Additionally, some parameters are not considered in the range of modulation because they are driven by others parameters. This is the case for:

- The top tube length that is defined by the seat tube angle and the positioning of the head tube via head angle, fork length and fork offset. Moreover, the reach and stack can substitute the top tube length in the definition of the geometry.
- The seat tube offset and stand over which depend directly from the seat tube length.

The Table 10 presents the minimum range of variation corresponding to the requirements imposed by Mr.Nicolai.

Geometry parameters	Minimum	Maximum
Head tube length	80	200
Wheel base	800	1400
Reach	300	600
Stack	200	600
Head angle	55	80
Seat angle	60	90
Bottom bracket drop	-80	+60
Effective chain stay length	300	550
Fork length	200	700
Fork rake	0	70

Table 10: Minimum range of modulation required for new welding-jig according to requirements

4.3 Development of a kinematic diagram

The welding jigs for tailor made frame available on market analyzed in the 2.4 all present an architecture based on an aluminum plate on which different units translate or rotate. This architecture brings rigidity to the structure and allows for a compact design easily maneuverable. However, this design requires an important machining work and does not provide an easy access to every side of the jig. For those reasons, it has been decided to build the welding jig using aluminum extruded profile inside a rectangular frame.

This solution has several advantages:

-It permits us to place the reference for the welding jig as the lower profile of the frame and define all the geometry from this reference. Thus defining the geometry as if the wheels were standing on the ground.

- The rectangular open frame allows for an easy access to the tubes in every direction.

- The use of Aluminum extruded profile reduces the number of parts to be machined. Indeed, components are easily available on the market to ensure the relative motion of standardized extruded profiles and can be used in the design of the welding jig.

The main requirement for the design of the welding jig was the possibility to display all the geometrical parameters on the jig and that some of those parameters were driving the setting of the jig. To fulfill this requirement, a kinematic diagram has been created to define the global architecture of the jig and the placement of the different joints regarding the geometrical parameters of the bicycle frame.

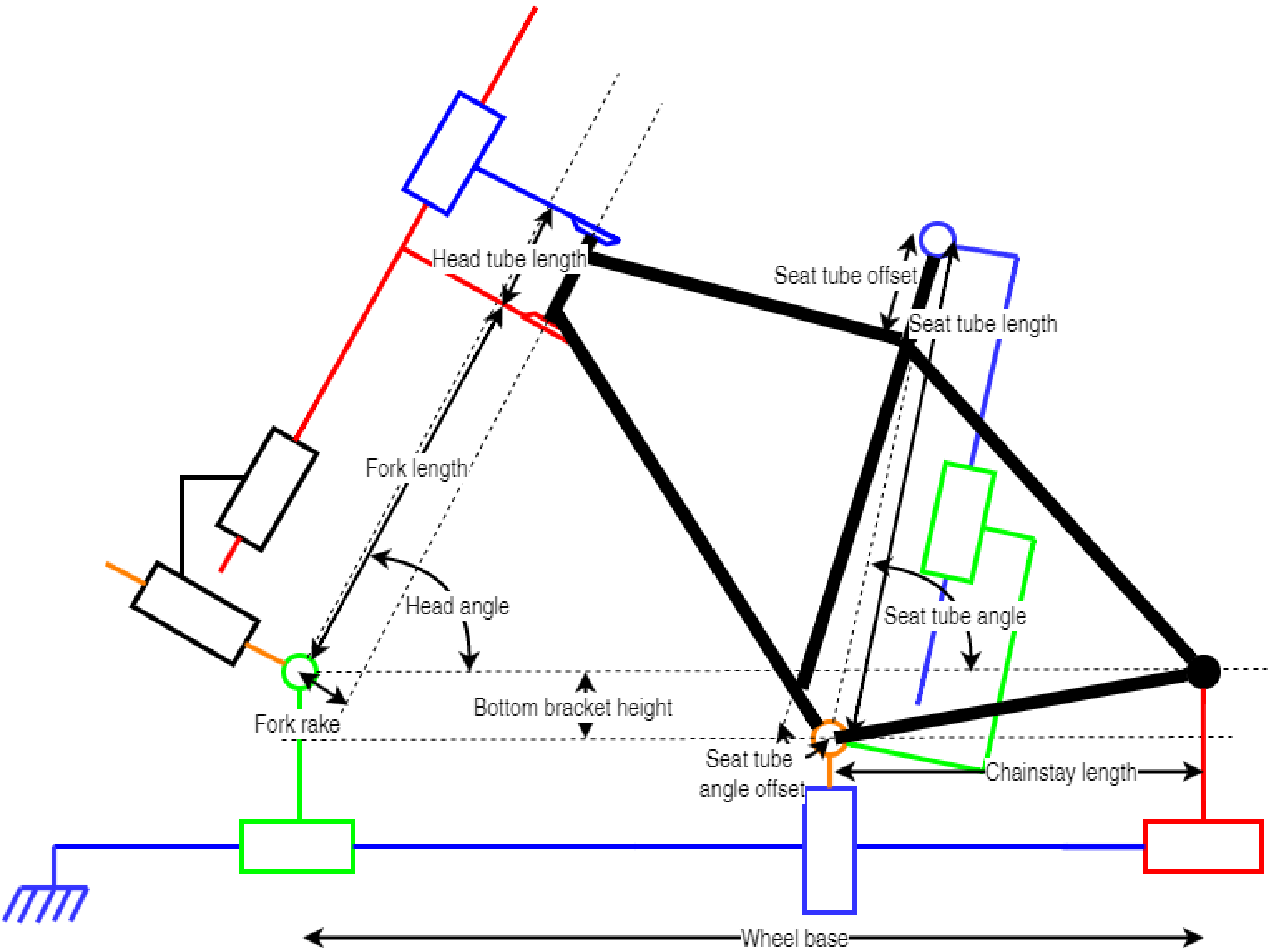


Figure 63:Simplified kinematic diagram of the new welding-jig

The kinematic diagram presented in the Figure 63 represents a simplified version of the jig where the holders for the top tube, down tube, chain stays and seat stays have been removed for clarification purposes.

The advantage of the design presented in Figure 63 is the possibility to set any parameter presented in this figure independently from each other. The design can be divided in three entities: the head tube entity, the seat tube entity and the drop out entity.

- Head tube kinematic design: the head tube is located via the real chain of geometrical parameters. First, the fork rake and fork length are adjusted according to the fork to be used with the frame, then the head tube is located via its lower and upper bores. Then, the whole entity is tilted according to the head angle and then translated to adjust the reach or wheelbase.

- The seat tube kinematic design: As we can see, the front and rear wheel are physically represented by their axes of rotation. Those axes being always at the same vertical distance from the reference extruded profile, they set the reference for the bottom bracket height. Once the bottom bracket located, the seat tube is tilted to the correct seat tube angle and the seat tube is locked via its top bore at the appropriate seat tube length. An additional device allows the seat tube to rotate around its highest point in order to adjust the seat tube angle offset while conserving the right seat tube length.

- Drop out kinematic design: The drop out is simply translated horizontally until the effective chain stay length is the one required.

The Figure 64 represents the kinematic diagram with the kinematic of the 4 tube holders H1, H2, H3 and H4. In a clarification purpose only the holding system H1 has been represented because H2, H3 and H4 present the same design. The kinematic design of the holders allows them to translate in any direction in the symmetrical plane of the frame and rotate easily to adapt to any geometry.

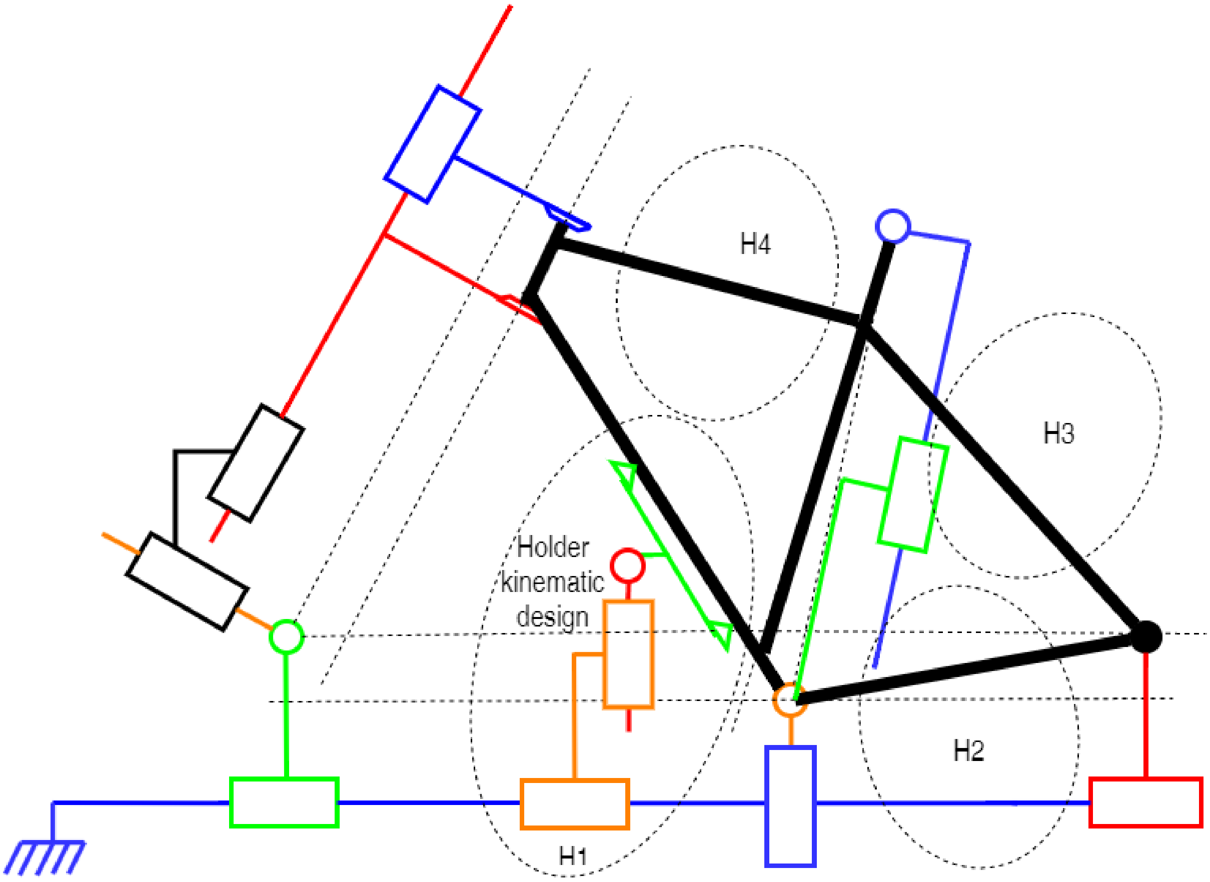


Figure 64: Kinematic diagram of the new welding-jig with tube holders

Finally, a measuring device displays easily the reach, the stack and the top tube length of the geometry. This system presented in the next section is independent and can therefore be removed while welding in order to facilitate the access to the tubes for the welder.

4.4 Design of the welding jig on SolidWorks

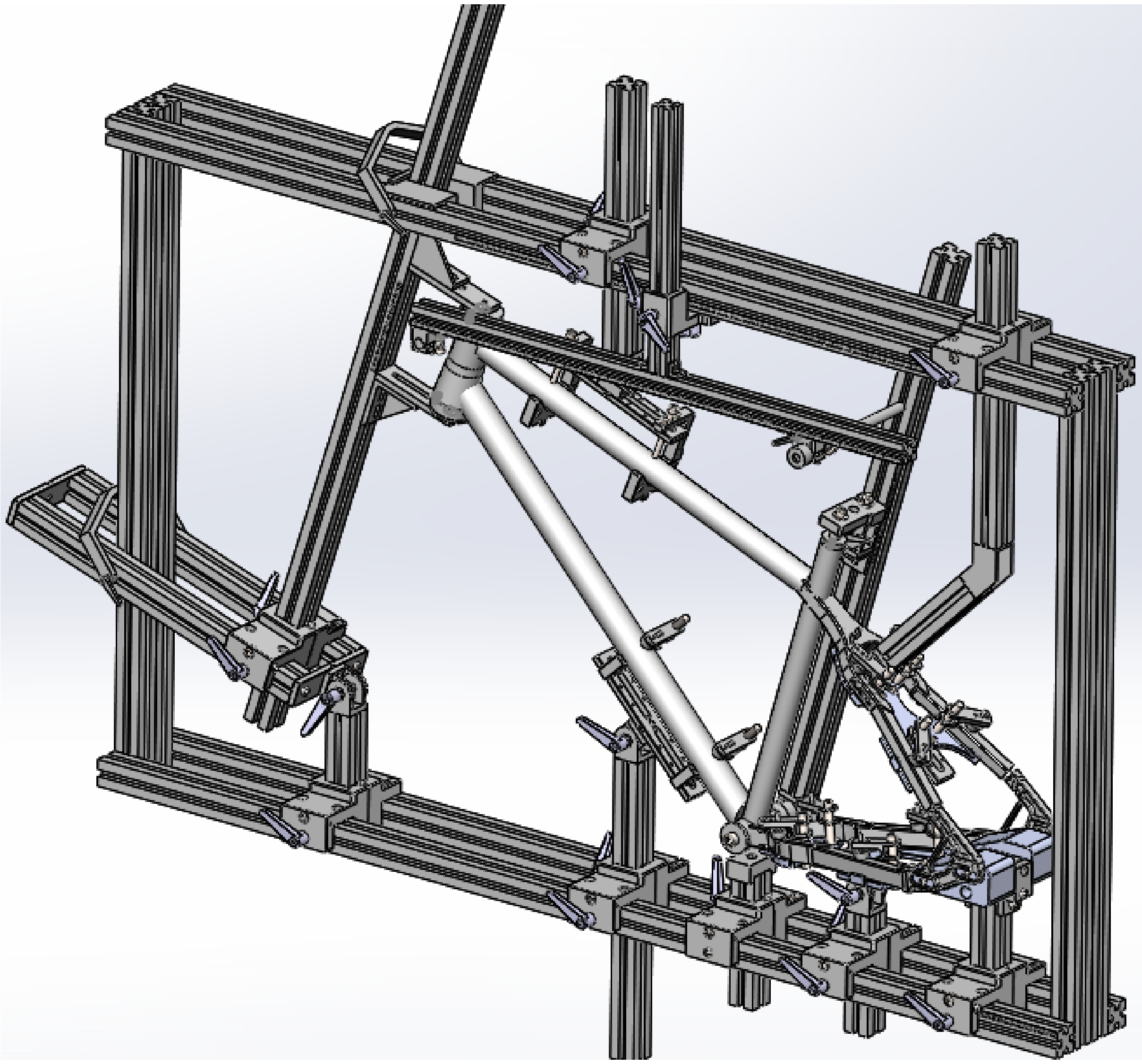


Figure 65: SolidWorks CAD model of the new welding-jig

In this section we will explain the technological choice made in order to design the jig following the kinematic diagram presented in the previous section and the requirements expressed by Mr. Nicolai. First, we will justify the choice of standard aluminum profile, then we will study the design of the translating and rotating units that forms the kinematic diagrams and finally we will go through each interface welding-jig/bicycle frame.

4.4.1 Main frame architecture

As presented in the previous section, the jig is constructed on a frame made by extruded aluminum profiles de type Bosch Rexroth (see Figure 61). Those extruded profiles are lightweight and present by their design a convenient solution for complex construction and movable entities.

Indeed, the Bosch Rexroth profile as a rectangular section with groove on each of its faces, those grooves allow nuts to slide inside and thus providing an easy displacement along those grooves. (see Figure 61). Moreover, the extruded profile can support a threaded insert at its extremities, thus allowing to connect profiles via their extremity and their faces.

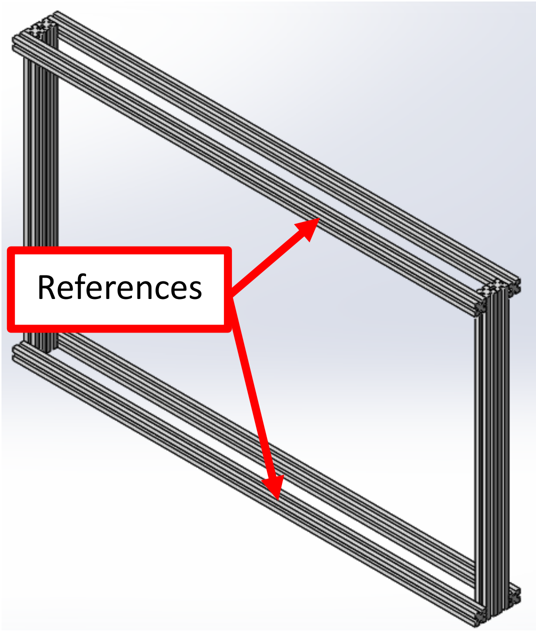


Figure 66: Main frame of the new welding jig design with the front lower and front upper profiles used as references

The section dimensions of the profiles selected to compose the frame and the components of the jig are 40x40 mm with a groove of 10mm width for M8 screws and special nuts. Those dimensions are the same as the dimensions of the profiles used on the current welding jig and have been selected for their good compromise between rigidity and lightness.

The main frame supporting all the moving entities is composed of two rectangular frames parallel to each other. This architecture locates the bicycle frame in the middle of the two frames thus balancing the masses and bringing more rigidity to the assembly. The main frame represented in Figure 66 is composed by four horizontal 40x40mm profiles and two 40x80mm that builds the vertical sides.

4.4.2 Translation unit designs

As we can see in the kinematic diagram, there are fifteen translation motions required and seven of them have for reference the lower or upper horizontal profiles. Those fifteen translation units have to ensure that the bicycle frame is always located in the same plane that is the plane of symmetry of the two frames composing the base of the welding jig. In order to do so, it has been decided to position all those translation units referring to the front lower or front upper profile (marked in red in the Figure 66).

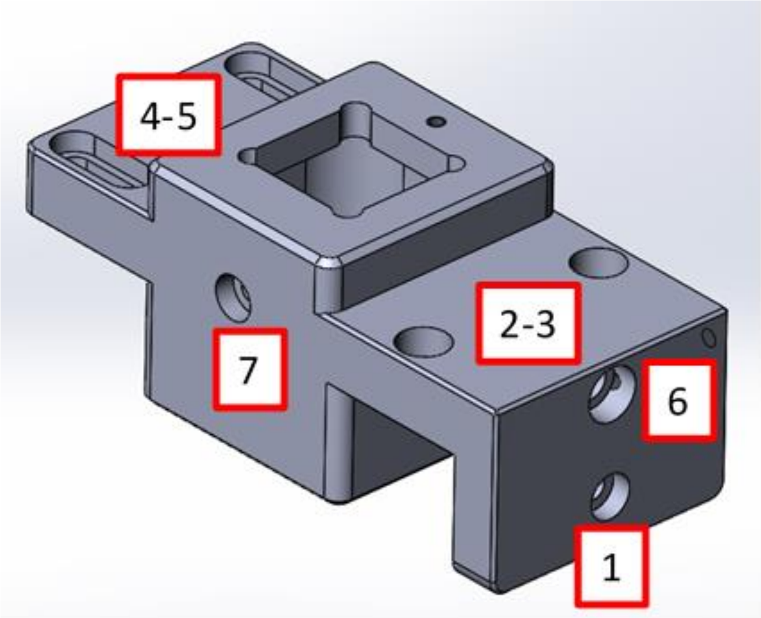


Figure 67: Details of translation unit with identification number of each the screw-holes for explanation

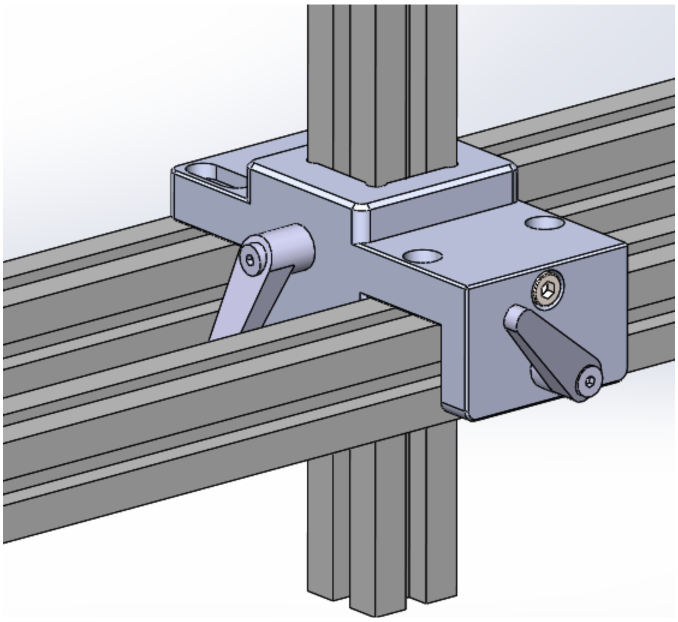


Figure 68: Translation unit assembled on the main frame of the welding-jig

The design shown in Figure 68 proposes as well to group two perpendicular translations into one unit. This combination allows us to use this part several times by simply locking one of the translations when required by tightening the corresponding screws. The two translations and their faces of positioning are represented in Figure 69 and Figure 70. The screws numbered 1 to 5 in Figure 67 control the positioning and the locking of the horizontal translation while the screws 6 and 7 the vertical one.

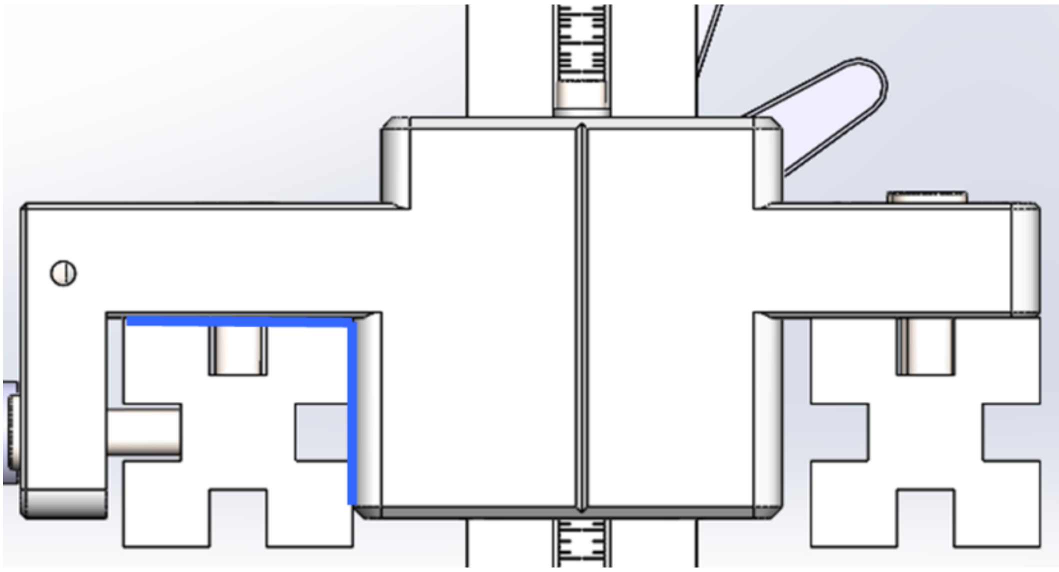


Figure 69:Faces of positioning in blue of the horizontal translation

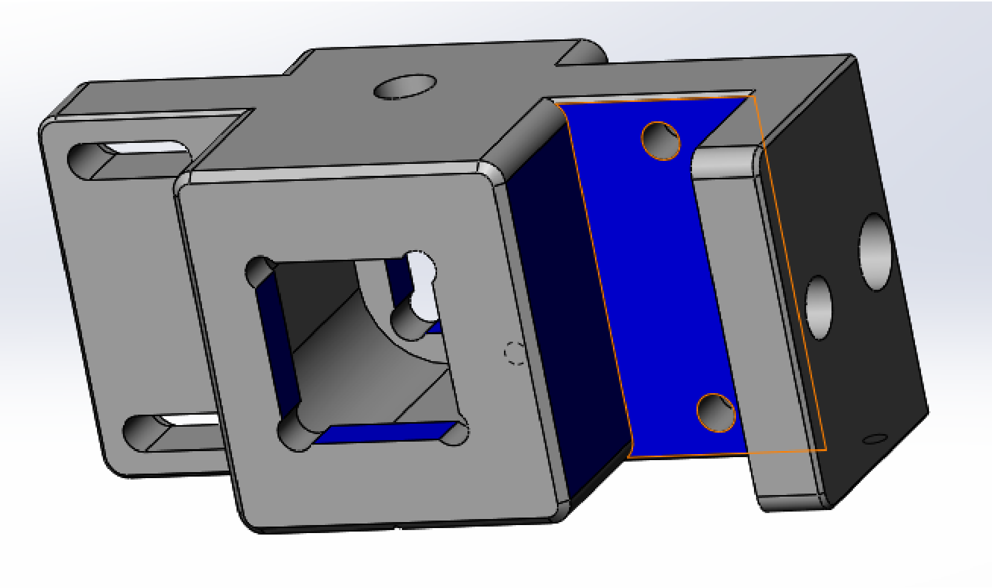


Figure 70: In blue: faces of positioning for vertical translation and upper positioning face for horizontal translation

In order to ensure the translation of the head tube interface or the seat tube interface along the extruded aluminum profiles representing the head angle or seat tube angle, some standardized parts have been used. Those parts, presented in Figure 71 and Figure 72, are available on the market and use simple extrusions that locates inside the groove of the profiles (marked on Figure 72).

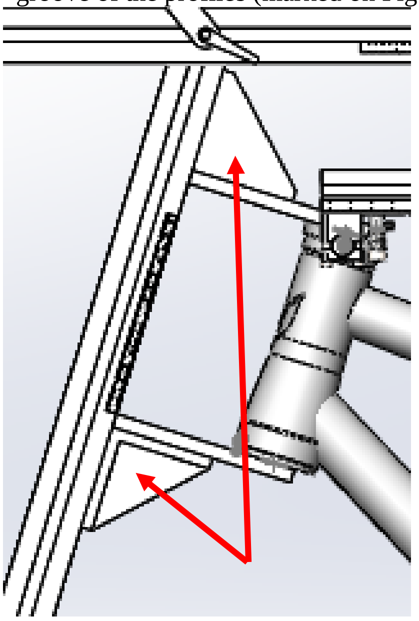


Figure 71: Location of standard bracket on the welding-jig

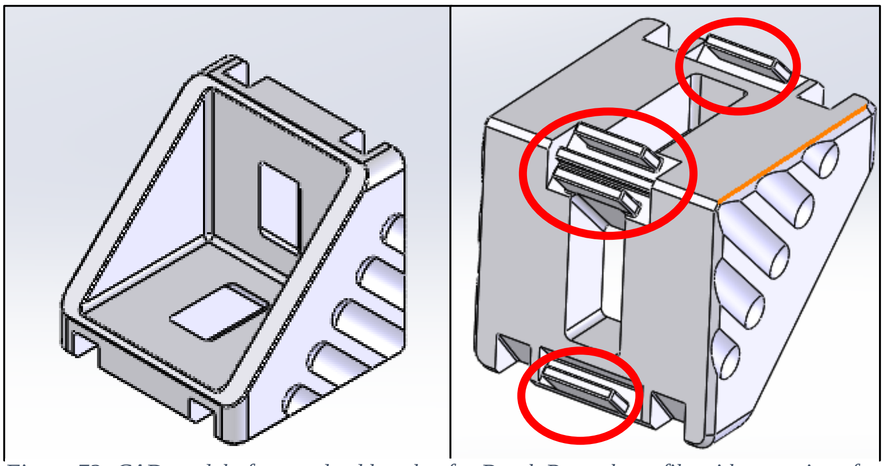


Figure 72: CAD model of a standard bracket for Bosch Rexroth profile with extrusions for sliding into the groove of the profile

4.4.3 Rotating unit designs.

The pivot joints presented in the kinematic diagram have been realized with standardized accessories for extruded aluminum profiles shown in Figure 73. This special joint ensures an easy and quick setting while giving the possibility to lock the rotation. For those reasons and additionally in order to reduce the numbers of parts machined in-house, this special joint presented in the Figure 74 has been used in every rotating joint of the kinematic diagram.

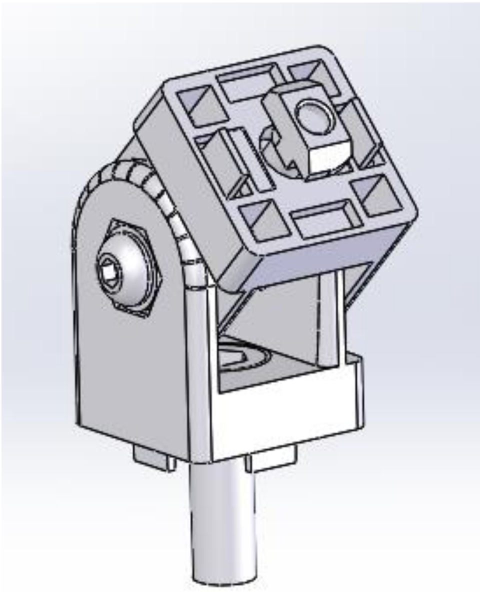


Figure 73: CAD model of a standard pivot joint for Bosch Rexroth profile

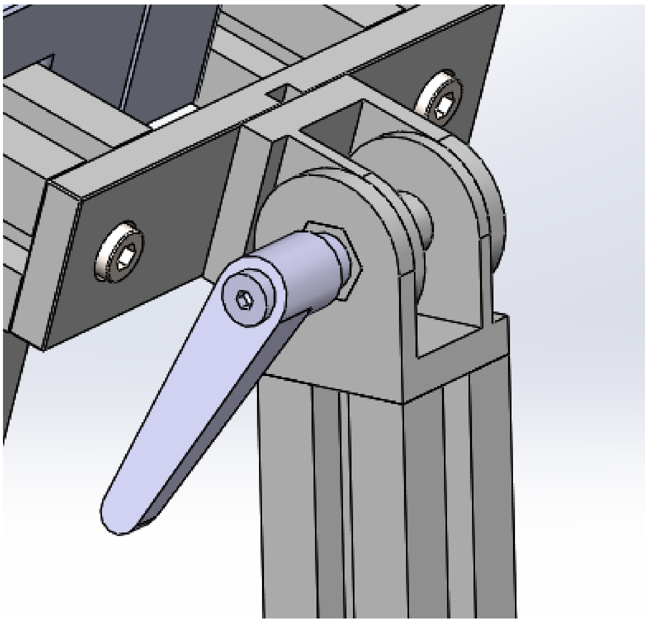


Figure 74: Pivot joint at the head angle setting on the welding-jig

4.4.4 Interfaces welding jig/ bicycle frame.

The translating and rotating joints ensure the displacement and the setting of the different geometrical parameters. However, the interfaces welding-jig/bicycle frame ensures:

- the localization of the frame in the jig.
- the compatibility with the different industry standards
- the locking of the frame while tacking.

Each of those interfaces being different, we will study their design separately.

- <u>Bottom bracket interface:</u>

The requirements for the bottom bracket interface are:

- Center the bottom bracket on the symmetry plane of the jig independently of the different bottom bracket widths.
- Ensure that the rotation of the seat tube is coaxial with the bottom bracket axis.
- Holding the bottom bracket unit in position while tacking.

The design proposed for this interface is presented in Figure 76. The interface is composed by three elements: one aluminum block that locates the axis of rotation for the bottom bracket and the seat tube profile, one inner axle that ensures that the two axes are coaxial and finally the adaptor for the bottom bracket width that aligns the frame in the symmetry plane of the welding jig. For the different bottom bracket width standards, an adaptor with a different length W (marked in Figure 75) is machined. The connection with the set tube profile is made via one half of the rotating unit presented previously.

- Head tube interfaces:

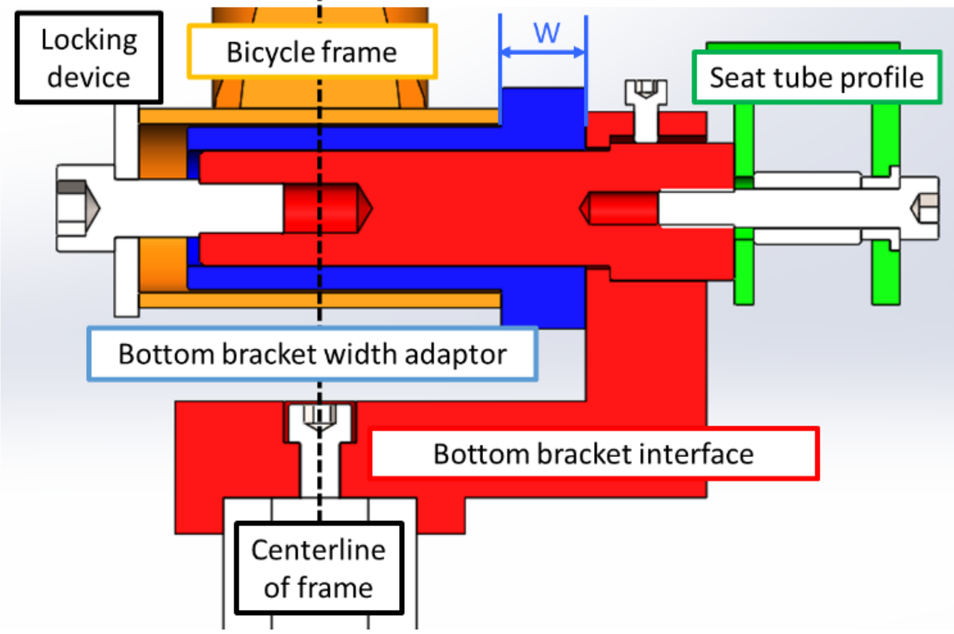


Figure 75: Cross section of the bottom bracket interface

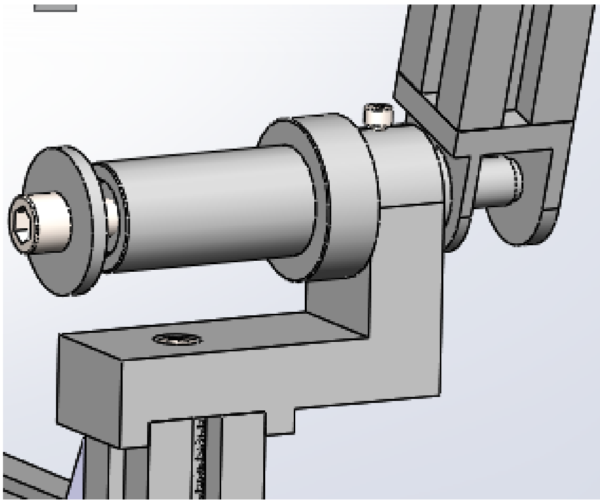


Figure 76: CAD model of the bottom bracket unit

The requirements for the head tube interface are:

- Locate the head tube by its upper and lower bore.
- Adapt to the different standards

The design presented in the Figure 77 is a revolution part that allows to accept every standard without change. Each shoulder has a length of 10mm in order to make the measurement of the fork length or head tube length easier (Figure 78). The countersink hole centers the interfaces on the plates to ensure the alignment between the upper and lower interface

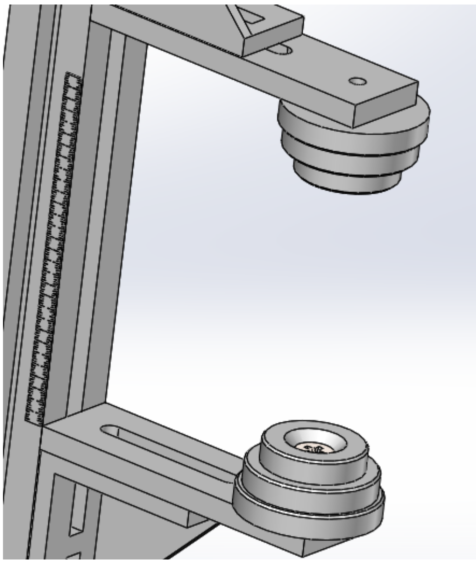


Figure 77: Head tube interface on welding-jig

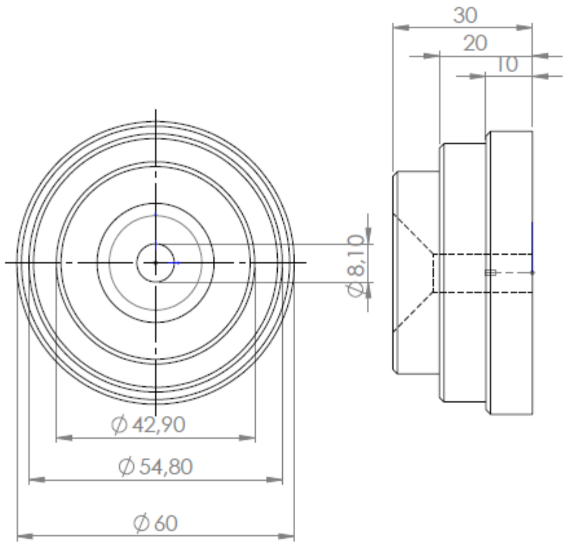


Figure 78: Drawing with dimensions of head tube interface

- <u>Seat tube interface:</u>

The requirements for the seat tube interface are:

- Certify the alignment of the seat tube to the center plane of the frame.
- Accept the different standards for seat tube inner diameters.
- Allow the rotation of the seat tube around its top end in order to retain the right seat tube length.

The design presented in Figure 79 and Figure 80 details the different components of this interface.

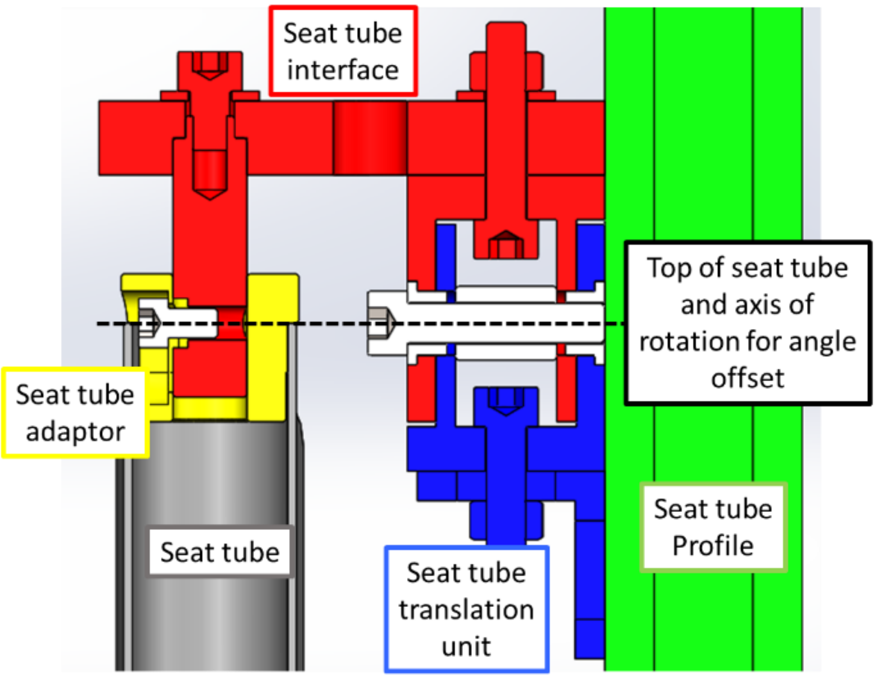


Figure 79: Cross section of the seat tube interface

In order to align the center of rotation for the angle offset and the top of the seat tube, a long hole has been machined in the adaptor. When changing the inner seat tube diameter, the adaptor can slide along its axle to guarantee the good alignment (see Figure 81). The interface can be removed quickly in order to facilitate the positioning of the tube before cutting. The groove and the shoulder marked in the figure provide an easy localization of the interface

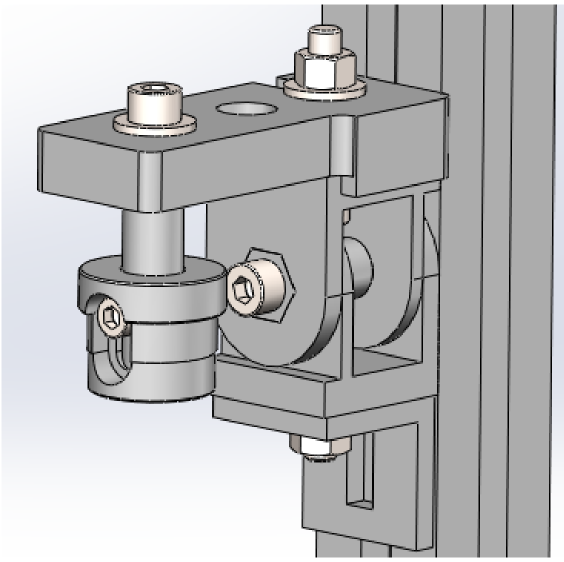


Figure 80: CAD model of the seat tube interface with bigger diameter

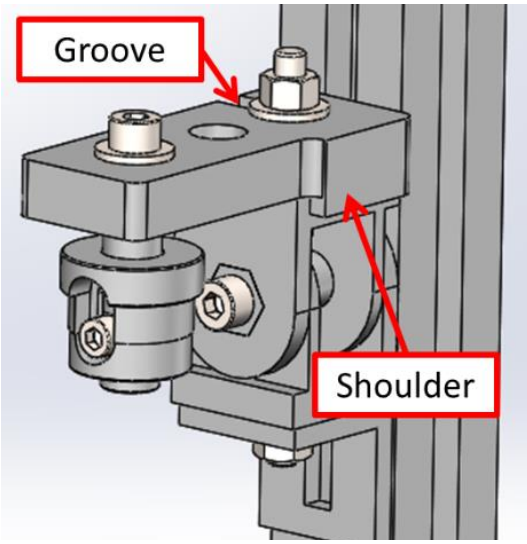


Figure 81: CAD model of the seat tube interface with smaller diameter

while replacing it.

- <u>Down tube and top tube interfaces:</u>

The down tube and top tube interfaces hold the down tube and top tube when tacking the frame. Those interfaces have to keep both tubes in the symmetry plane of the jig and be compatible with different tube sizes. The design proposed for those interfaces is presented in Figure 82 and Figure 83.

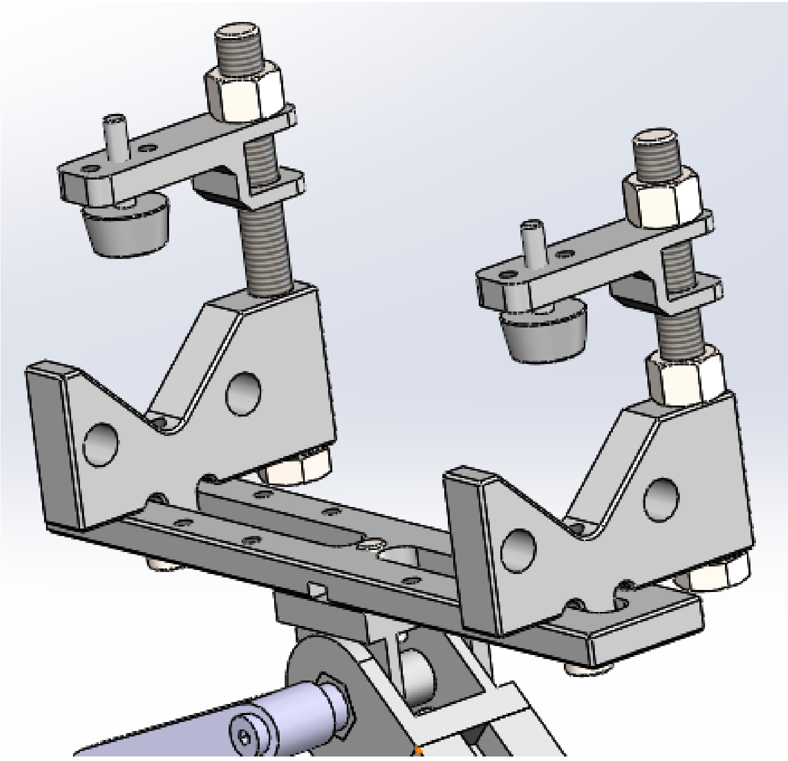


Figure 82: Down tube interface

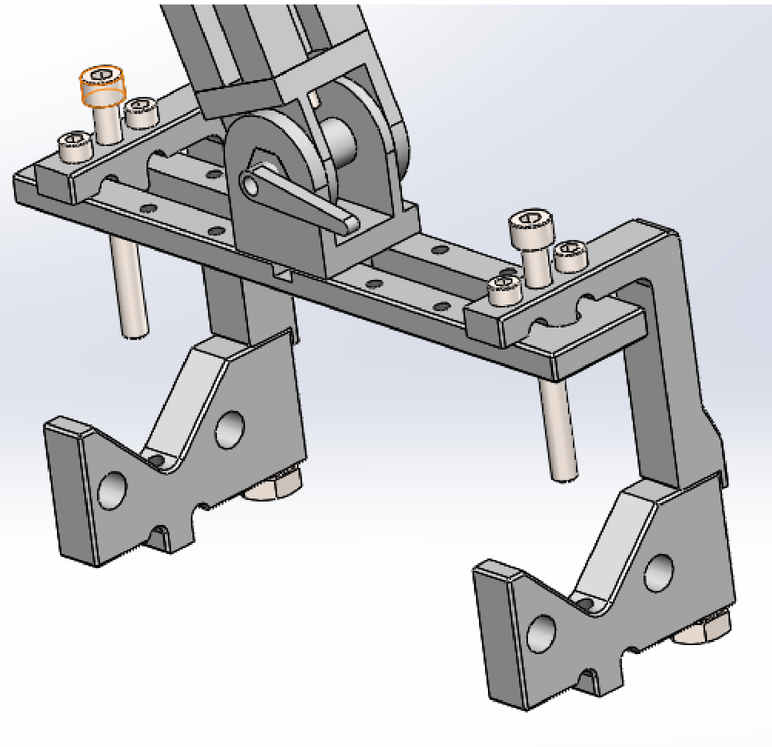


Figure 83: Top tube interface

Both interfaces use the same base plate on which the V-holders can translate. The V-holders have the same design in the two interfaces in order to reduce the machining load.

- <u>Drop-out interface</u>

The requirements for the drop out interface are to:

- Locate the right and left drop-out from the rear wheel axle.
- Be compatible with the variances of drop-outs.
- Maintain the drop-outs while tacking.

Figure 84 presents the interface without any adaptor. The cylinder marked in blue represent the rear wheel axle while the red cylinder is used as complementary interface with the adaptors (see Figure 85)

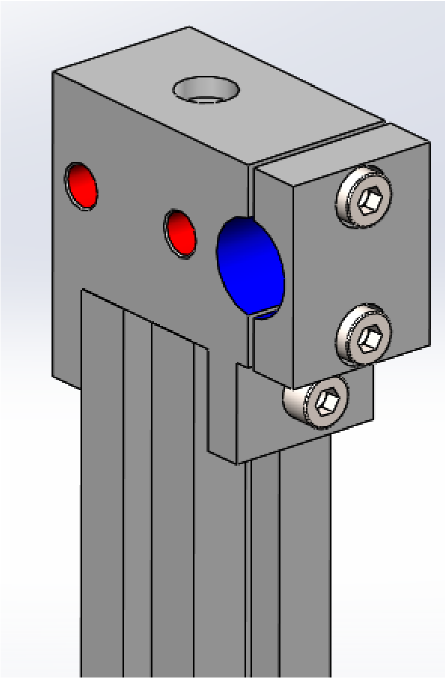


Figure 84: Dropout interface without adaptor

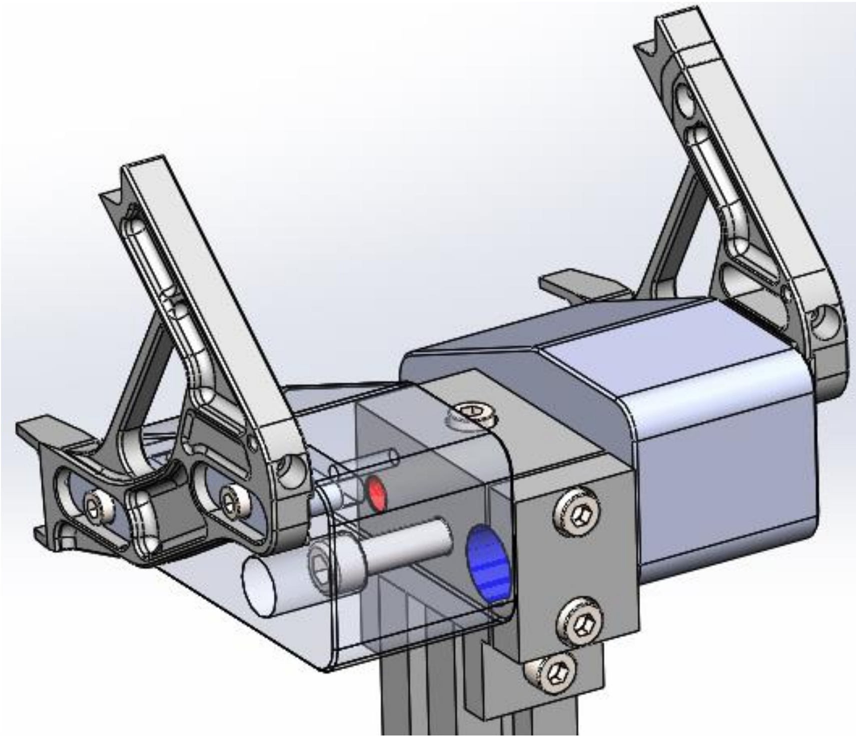


Figure 85: Adaptor for 148x12 axle on argon GLF drop-outs

<u>Chain stays and seat stays interfaces:</u>

The requirements for the chain stays or seat stays interface are to:

- Position the hoof and yoke respectively in alignment with the chain stays and seat stays.
- Be compatible with any hoof or yoke design.
- Ensure the symmetry of the group hoof + chain stays or yoke + seat stays regarding the symmetry plane of the jig.
- Allow any position/orientation of the group hoof + chain stays or yoke + seat stays in order to align it with the drop outs and the bottom bracket or top tube.
- Give an easy access to the junction hoof/chain stays or yoke/seat stays for the tacking.
- Maintain the group hoof + chain stays or yoke + seat stays while tacking.

For those interfaces, presented in Figure 86 and Figure 87, the motion is provided by the same assembly of the translation unit and the rotating unit aas on the top and down tube holders. Moreover, the chain stays interface uses the same base plate than the top and down tube in order to fix the adaptor for each hoof or yoke design.

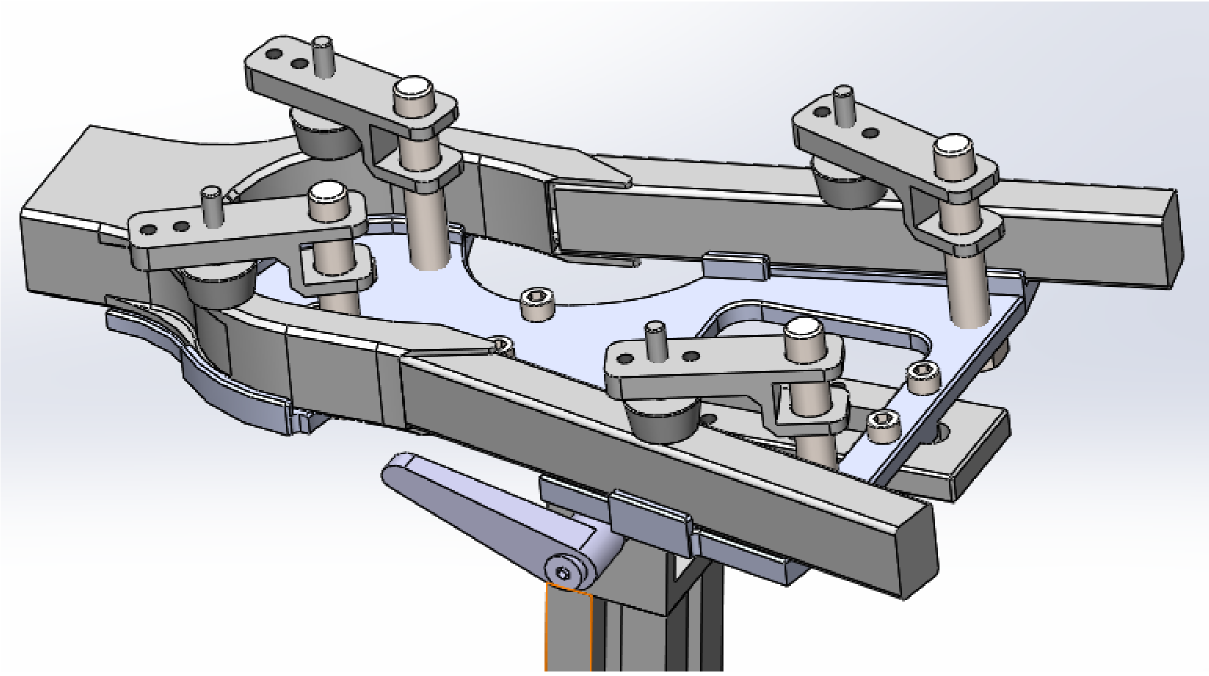


Figure 86: Chain stays interface with adaptor for Argon GLF

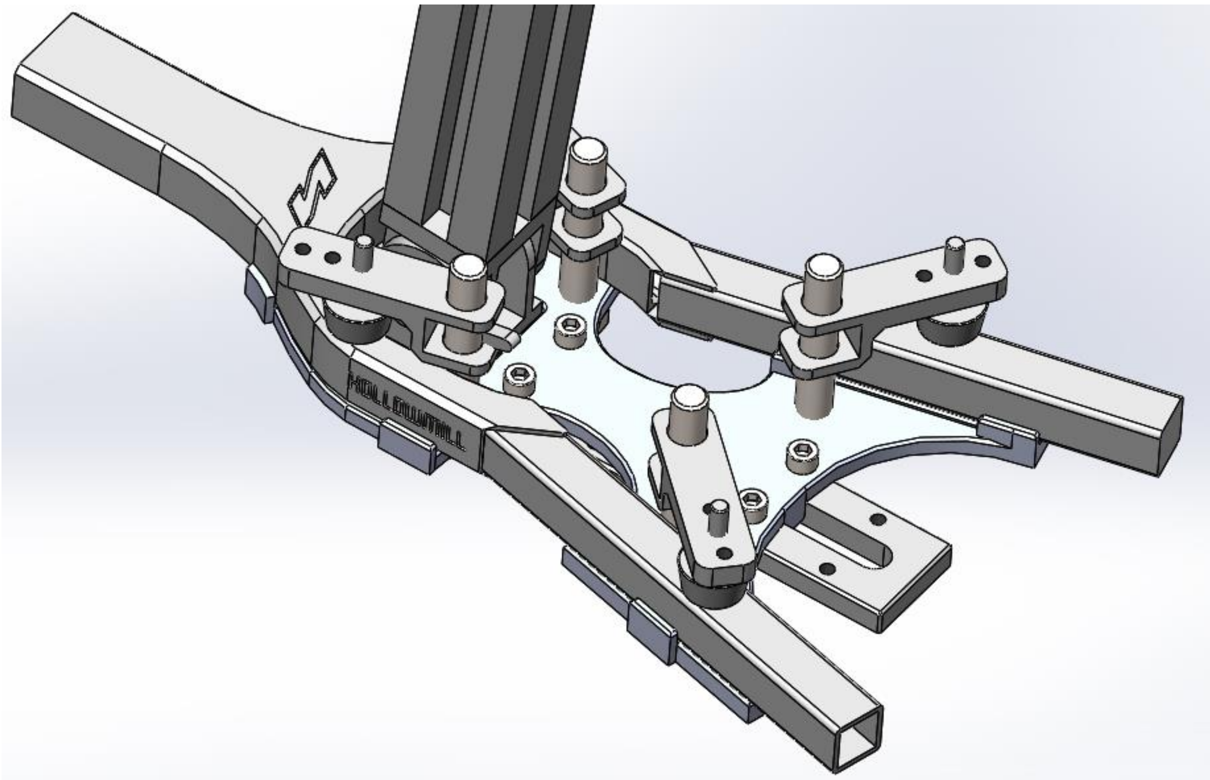


Figure 87: Seat stays interface with adaptor for Argon GLF

The complete design of the welding jig for the Argon GLF is presented in Figure 88 As we can see, the welding jig also includes a measuring device (marked in blue). The purpose of this measuring device is to display the reach, stack and top tube length of the frame. The measure is based on the system explained in Figure 88.

The stack is measured by a combination of the length L2 known via the bottom bracket height and L1 which can be read on the green ruler on the measurement device. The reach is measured directly on the ruler represented in orange while the top tube length is measured directly on the device.

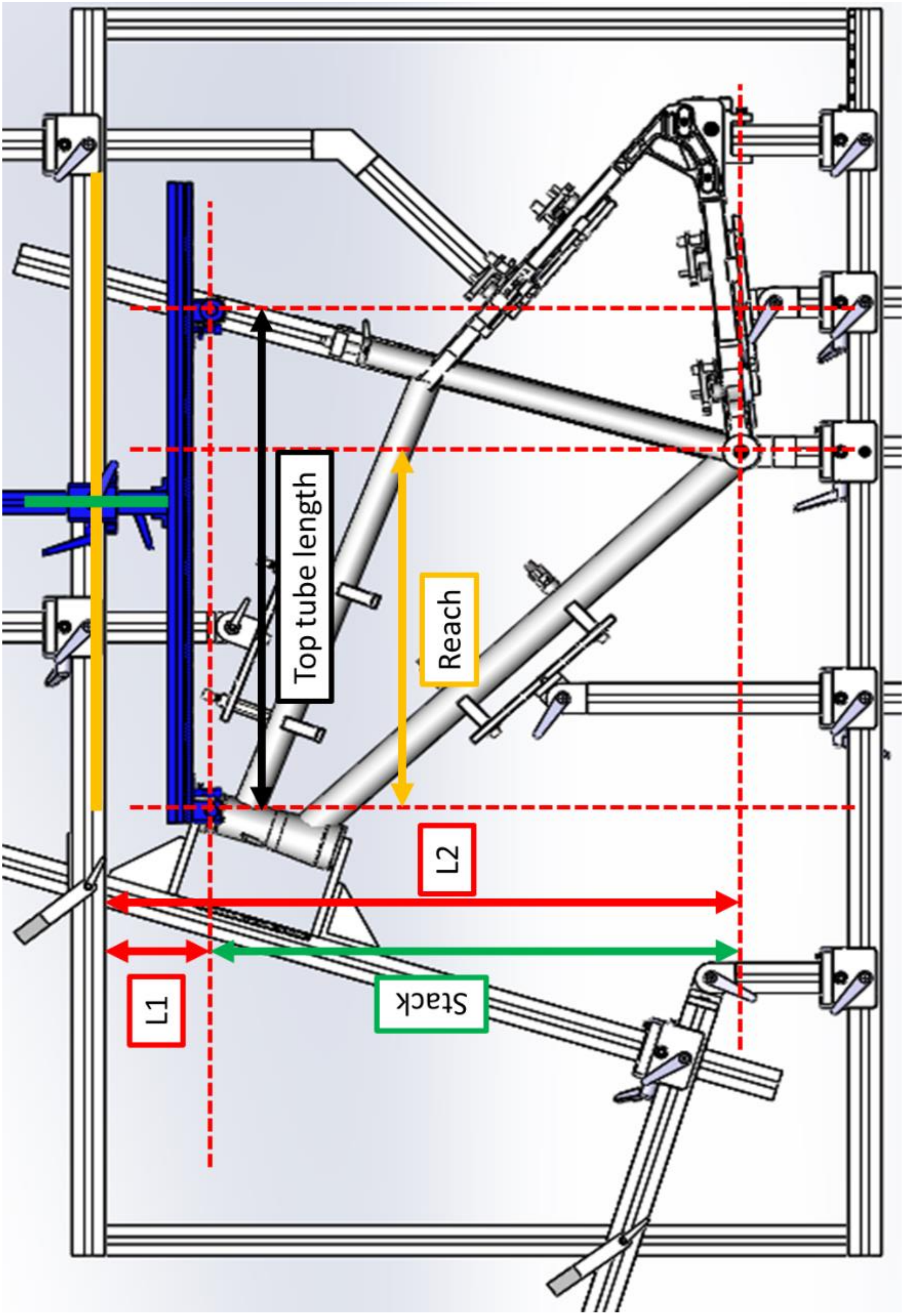


Figure 88: Details of reach, stack and top tube length measuring system

The location of the top of the head tube is made via a laser beam and the location of the seat tube axis is made via a pin in the groove of the profile (see Figure 89 and Figure 90). The laser and the pin are both hold via a V-holder that translates in the groove of the aluminum extruded profile. This horizontal extruded profile translates vertically on the main frame of the jig via a translation block (see Figure 91) using a similar architecture than the translation unit presented at the beginning of this section.

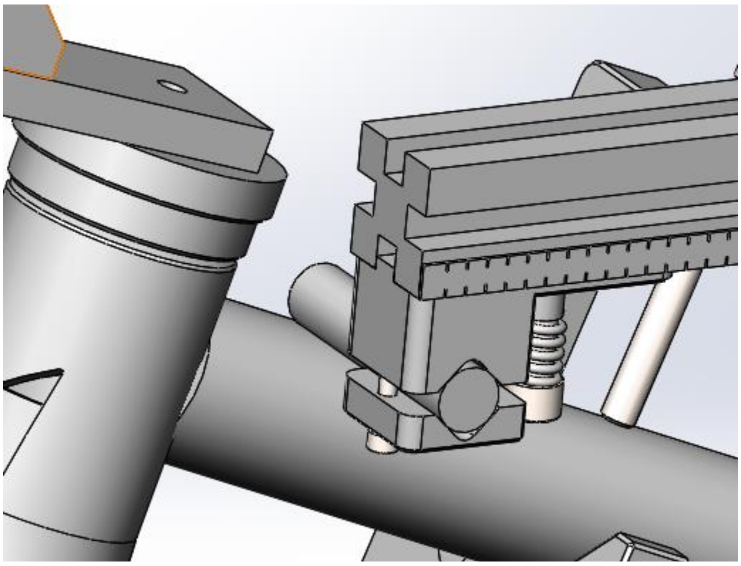


Figure 89: Laser device for locating the top of the head tube

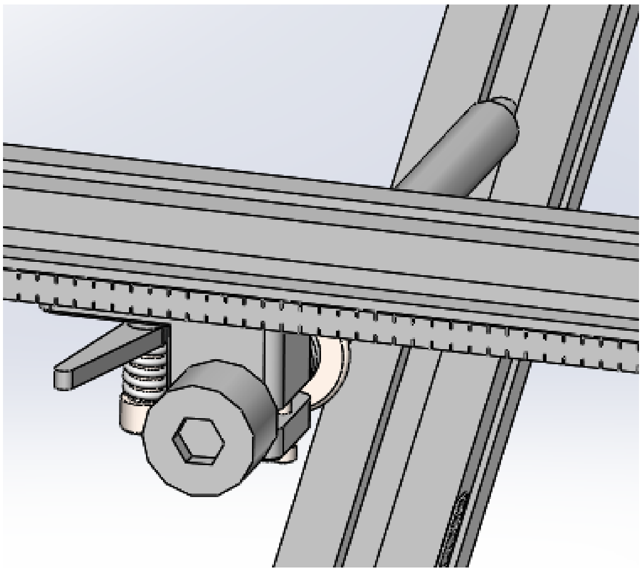


Figure 90:Pin device for locating inside the groove of the seat tube profile

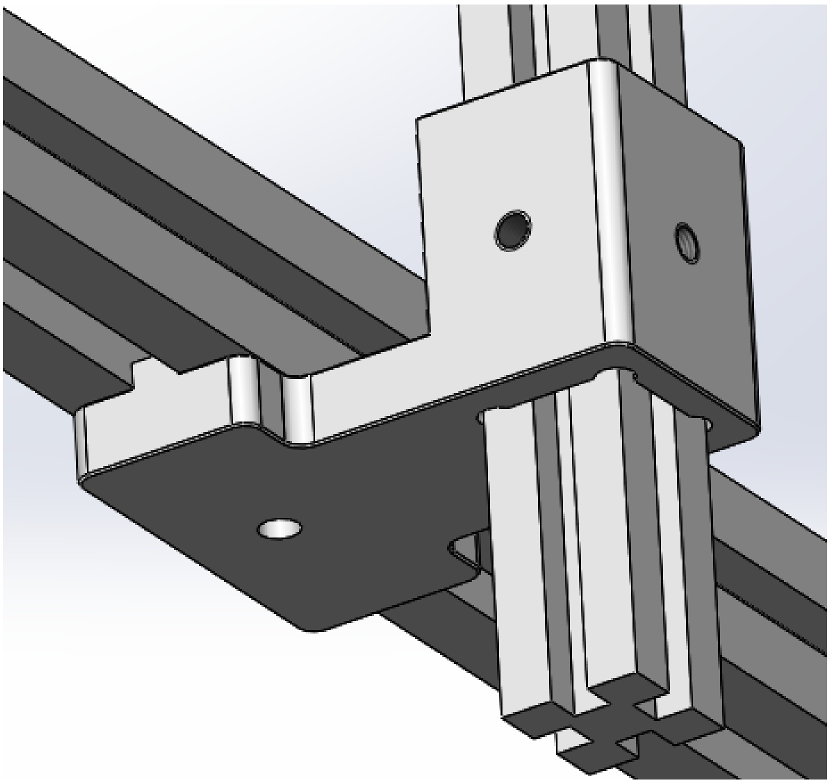


Figure 91: Translation block for reach, stack and top tube measurement device

4.4.5 Choice of dimensions

All the extruded profiles translating or rotating have been dimensioned in order to fulfill the requirements of variation of each parameter. According to the CAD software Solid works, the final range of variation of this design is presented in the Table 11. We can therefore conclude that the design presented fulfill all the initial requirements.

Geometry parameters	Minimum	Maximum
Head tube length	<20	>200
Wheel base	<200	1470
Reach	<300	640
Stack	<200	700
Head angle	<55	>80
Seat angle	<60	>90
Bottom bracket drop	-80	+60
Effective chain stay length	<300	550
Fork length	<200	>700
Fork rake	0	70

Table 11: Comparison of the modulation range of the welding jig designed with the requirements

4.5 Manufacturing of the welding jig

Although the use of standard components limited the numbers of part to be machined, the interfaces welding-jig/bicycle frame are specific to Nicolai GmBH. They cannot be found on a market and have to be machined in-house. In this section we will go through the machines and tools used for the manufacturing of the parts, then we will review the material and fixtures used for every interface.

4.5.1 Machines

The priority being given to the manufacturing of bicycle parts; the manufacturing of the jig has been spread over three months due to the lack of machines available. It has been carried out on several machines. Those machines were all operated by qualified technicians who programmed in G-code the machining using the Cam Works software. The machines are presented quickly in this section:

- Brother TC-32BN QT + additional rotary table Lehman EA-410.1A (4 axis: X, Y, Z, A): see Figure 92 and Appendix 11: CNC machine description for description.


Figure 93: Brother TC-32AN

- Brother TC-32AN: 3 axis CNC milling machine


Figure 92: Brother TC-32BN QT

- Doosan Lynx 220: 2 axis CNC turning machine.

Figure 94: Doosan Lynx 220

4.5.2 Tools

The Figure 95 shows some of the drilling and milling tools used in the machining of the parts. As we can see those tools can be divided in six different categories that we will present individually.

Figure 95: Sample of drilling and milling tools used in the machining of the parts

- Face milling tool

In order to set the primary reference of each machining process, a face milling tool machines a plane on of the faces of the raw stock material. The tool used at Nicolai GmBH is an 8 teeth and 50mm diameter face milling tool with cemented carbide cutting inserts. This tool is presented in Figure 96.

Figure 96: Face milling tool

- Centering drills

In order to ensure that every hole is drilled properly, a centering drill centers every one of them. Moreover, those centering drills are also used to machine the chamfers on edges of the parts. All centering drills are made of cemented carbide and present a 90-degree point angle in order to machine 45-degree chamfers. All the centering drills used in the machining of the parts are presented in the Figure 97 with their diameters in millimeters.

Figure 97: Centering drills of 5, 10 and 20mm

- Drills and tapping tools

Cemented carbide drills have been used to machine screw-clearance holes or tap-drill holes. The list of drills used during the machining of the parts is presented in the Table 12.

Figure 98: example of drill used in the machining

Drill diameter in mm	Type of hole
4	Tap-drill M5
5,1	Screw clearance M5
5	Tap-drill M6
6,1	Screw clearance M6
6,8	Tap-drill M8
8,1	Screw clearance M8
8,5	Tap-drill M10
10,1	Screw clearance M10
10,3	Tap-drill M12
12	Straight hole
12,5	Screw clearance M12

Table 12: List of drills used in the machining

Figure 99: Tap drills used in the machining

In addition to drills, tapping tools have machined the threads for the screw connection between the different parts. The tapping tools are made of High Speed Steel (HSS) and the diameters used in this project are M5, M6, M8, M10, M12 (see Figure 99).

- Roughing end mill and finishing end mill

The tools used during the milling operations are cemented carbide mills with 3 teeth. The difference in material removal capacity between the roughing and finishing end mills comes from the bigger number of cutting edges on the roughing end mill. This number of cutting edges is increased via “wavy edges” that can be seen in the Figure 100. This figure shows some of the roughing end mill used in the production process while the Figure 101 show some of the finishing end mill used. The diameter used during the production processes are: 6mm, 8mm, 10mm and 16mm.

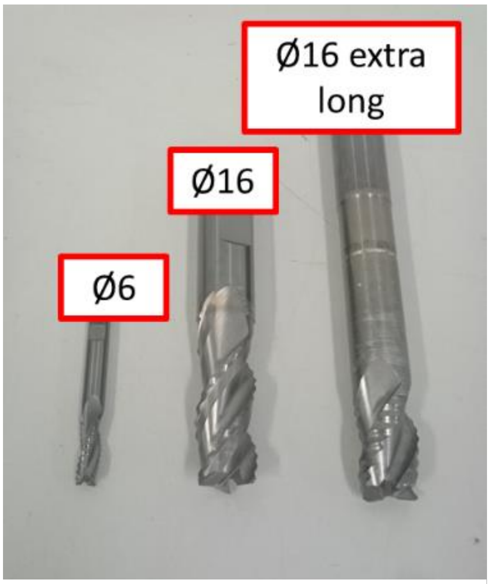


Figure 100: Roughing end mill used in the machining

Figure 101: Finishing end mill used in the machining

- T-slot milling cutter

In order to mill the pocket inside the translation unit, a T-slot milling tool has been used. This 3-teeth tool represented in the Figure 102 is made of cemented carbide and has diameter of 27,7mm with an offset of 4mm.

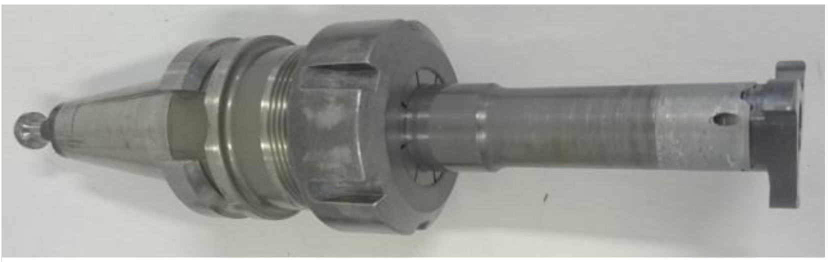


Figure 102: T-slot milling tool

4.5.3 Machining of welding jig parts

In this section, we will explain the choice of material for the different interfaces and then present the manufactured components of each interface as well as the fixture used.

4.5.3.1 Choice of material for interfaces welding-jig/bicycle frame

According to the requirements expressed by Mr. Nicolai, the welding jig to be manufactured has to be lightweight for easy maneuverability and to be compatible with the welding process.

The welding jig purpose is to maintain the different components of the frame while tacking. Indeed, the complete welding will be carried out outside of the jig for better access to the frame for the welder. For this reason, we can consider that the welding time is too short to cause any important thermal distortion to the interface itself. Moreover, Nicolai GmBH only manufactures aluminum frames. Thus keeping the welding temperature low. For those reasons and because it will reduce the overall weight of the jig, we can use aluminum alloy as the main material for our parts. However, some interfaces are made in steel to provide a longer durability in the time or because subjected to a high concentration of tacking zones around them.

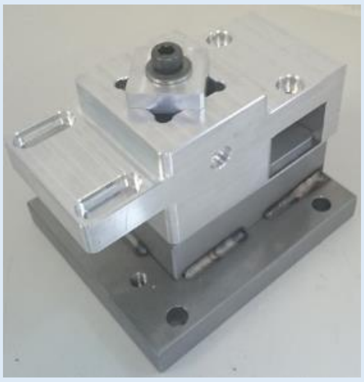
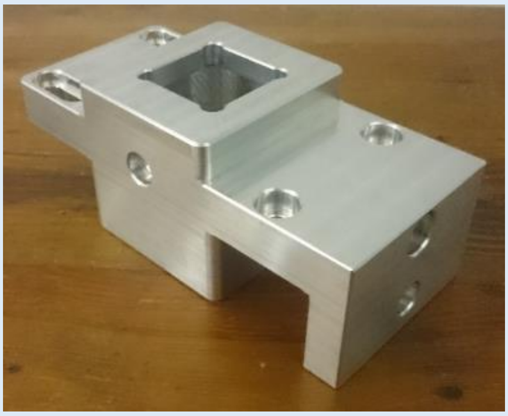
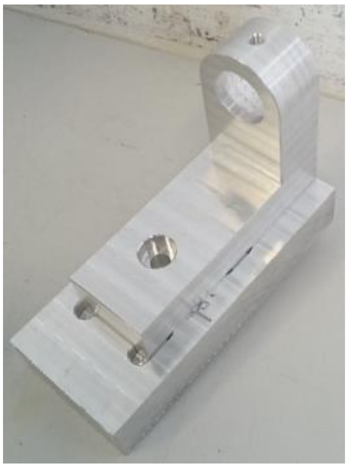
The aluminum alloy selected for the welding jig is the alloy EN-AW-7020 that is the same than the alloy used for the manufacturing of the machined components of the bicycle frame. If this alloy has been selected because it was available in the company, it also has one advantage. Indeed, the use of the same material as the bicycle frame components will reduce the contamination of the material while tacking.

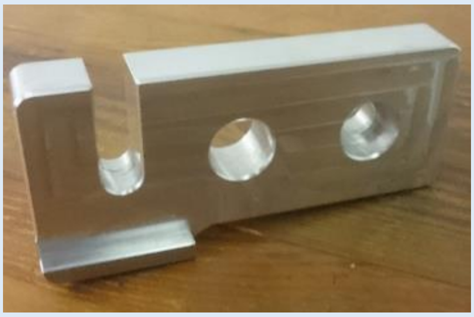
In the case of the Bottom bracket adaptor, the chain stays adaptor and the seat stays adaptor (detailed in next section), the material used is the S235 following the norm EN10025 (SS 13.11.00 for the Swedish norm).

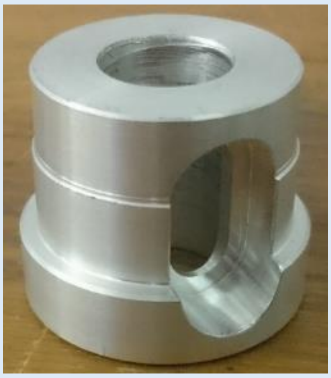
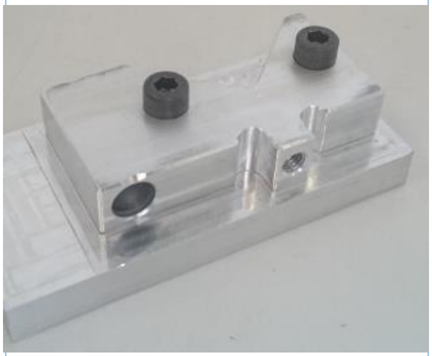
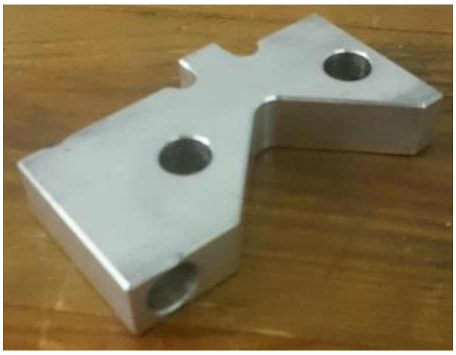
4.5.3.2 Machining and fixtures of interfaces welding-jig/bicycle frame

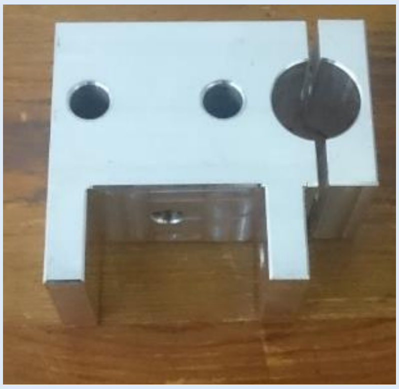
For each different part, we will present the finished part and the special fixture designed for the machining if required. As every part machined with the CNC milling machines is initially a rectangular shaped block of aluminum, a first operation of face milling is carried to provide a face of reference for the following operations. For this operation, the raw block is clamped into the vice of the machine as seen in the Figure 103. This clamping will not be described again in each interface process as it is common for all of them.

Figure 103: Vice in the CNC machine

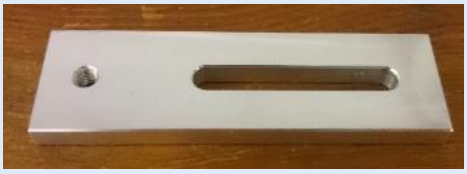
Name	Description	Dedicated fixture	Finished part
Translation unit	Material: EN-AW-7020 Machine: Brother TC-32BN QT Number: 7 Machining time: 24 min 30 sec		
Bottom bracket interface-Main block	Material: EN-AW-7020 Machine: Brother TC-32BN QT Number: 1 Machining time: 15min 01sec	 	

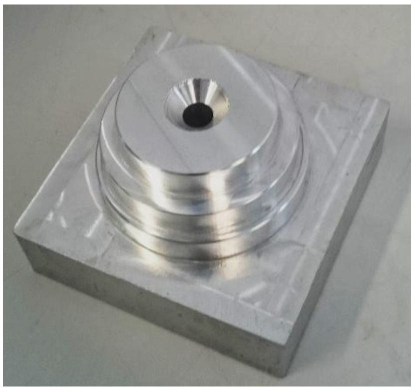
Bottom bracket interface-axle	<u>Material:</u> S235 <u>Machine:</u> Doosan Lynx 220 <u>Number:</u> 1 <u>Machining time:</u> 3 min 09 sec *Steel has been selected for durability of the thread supporting all the seat tube profile and interfaces*	No dedicated fixture. The axle is clamped in the chuck	
Bottom bracket interface-adaptor	<u>Material:</u> S235 <u>Machine:</u> Doosan Lynx 220 <u>Number:</u> 5 (1 for each standard) <u>Machining time:</u> 4 min 30 sec *Steel has been selected because the higher concentration of tacking zone around the bottom bracket*	No dedicated fixture. The axle is clamped in the chuck	
Seat tube interface-Main plate	<u>Material:</u> EN-AW-7020 <u>Machine:</u> Brother TC-32A <u>Number:</u> 1 <u>Machining time:</u> 4min 31 sec		

Seat tube interface- Axle for adaptor	Material: S235 Machine: Doosan Lynx 220 (turning) Brother TC-32A (milling) Number: 1 Machining time: 1 min 09 sec	No dedicated fixture in the Lathe. The axle is clamped in the chuck	
Seat tube interface- Axle for adaptor	Material: EN-AW-7020 Machine: Doosan Lynx 220 (turning) Brother TC-32A (milling) Number: 1 Machining time: 1 min 35 sec	No dedicated fixture in the Lathe. The adaptor is clamped in the chuck	
Down tube and top tube interface- V holders	Material: EN-AW-7020 Machine: Brother TC-32BN QT Number: 4 Machining time: 8 min 20 sec		

Down tube, top tube, chain stays interface- Base plate	<u>Material:</u> EN-AW-7020 <u>Machine:</u> Brother TC-32A <u>Number:</u> 3 <u>Machining time</u> 4 min 12 sec	No dedicated fixture, the plate is simply held in the vice.	
top tube interface- vertical link to V holders	<u>Material:</u> EN-AW-7020 <u>Machine:</u> Brother TC-32A <u>Number:</u> 2 <u>Machining time</u> 10 min 07 sec		
Drop out interface- Main block	<u>Material:</u> EN-AW-7020 <u>Machine:</u> Brother TC-32A <u>Number:</u> 1 <u>Machining time</u> 9 min 40 sec	Photo of fixture is not available	

Drop out interface-Adaptor GLF	<u>Material:</u> EN-AW-7020 <u>Machine:</u> Brother TC-32A <u>Number:</u> 1 <u>Machining time</u> 15 min 40 sec		P 
Seat stay interface-Main plate	<u>Material:</u> EN-AW-7020 <u>Machine:</u> Brother TC-32A <u>Number:</u> 1 <u>Machining time:</u> 6 min 34 sec	No dedicated fixture, the plate is simply held in the vice.	
Seat stay interface-Adaptor GLF	<u>Material:</u> S235 <u>Machine:</u> Brother TC-32A <u>Number:</u> 1 <u>Machining time:</u> 23 min 14 sec		

Chain stay interface – Adaptor GLF	Material: EN-AW-7020 Machine: Brother TC-32BN QT Number: 1 Machining time: 24 min 45 sec		
Measuring unit- Laser holder	Material: EN-AW-7020 Machine: Brother TC-32BN QT Number: 1 Machining time: 5 min 31 sec		
Head tube interface- Holding plate for adaptor	Material: EN-AW-7020 Machine: Brother TC-32A Number: 2 Machining time: 3 min 07 sec	No dedicated fixture, the plate is simply held in the vice.	

Head tube interface-Cylindrical adaptor	Material: EN-AW-7020 Machine: Brother TC-32A Number: 2 Machining time: 10 min		

Once all the parts have been manufactured, the jig can be assembled. However, the welding jig needs to guarantee the exactness of the measurement displayed on it. To do so, the calibration described in the next section is carried out all along the assembly of the welding jig.

4.6 Calibration of the welding jig

The calibration of the welding jig is an important step of the project as it will determine the final quality of the product. This calibration is carried from the start of the assembly until the end. Firstly, the measurements displayed on the jig are presented in the Figure 104. In this figure we can observe that the vertical reference is composed by the front and rear axle while the horizontal reference is defined by the bottom bracket axis.

In this section we will go through the different step of calibration of those references and measurements. It is important to notice that every ruler is placed with an offset of 2 or 3 millimeters in order to be able to correct a possible misplacement of the ruler by placing spacers before the needle of measurement (see Figure 105).

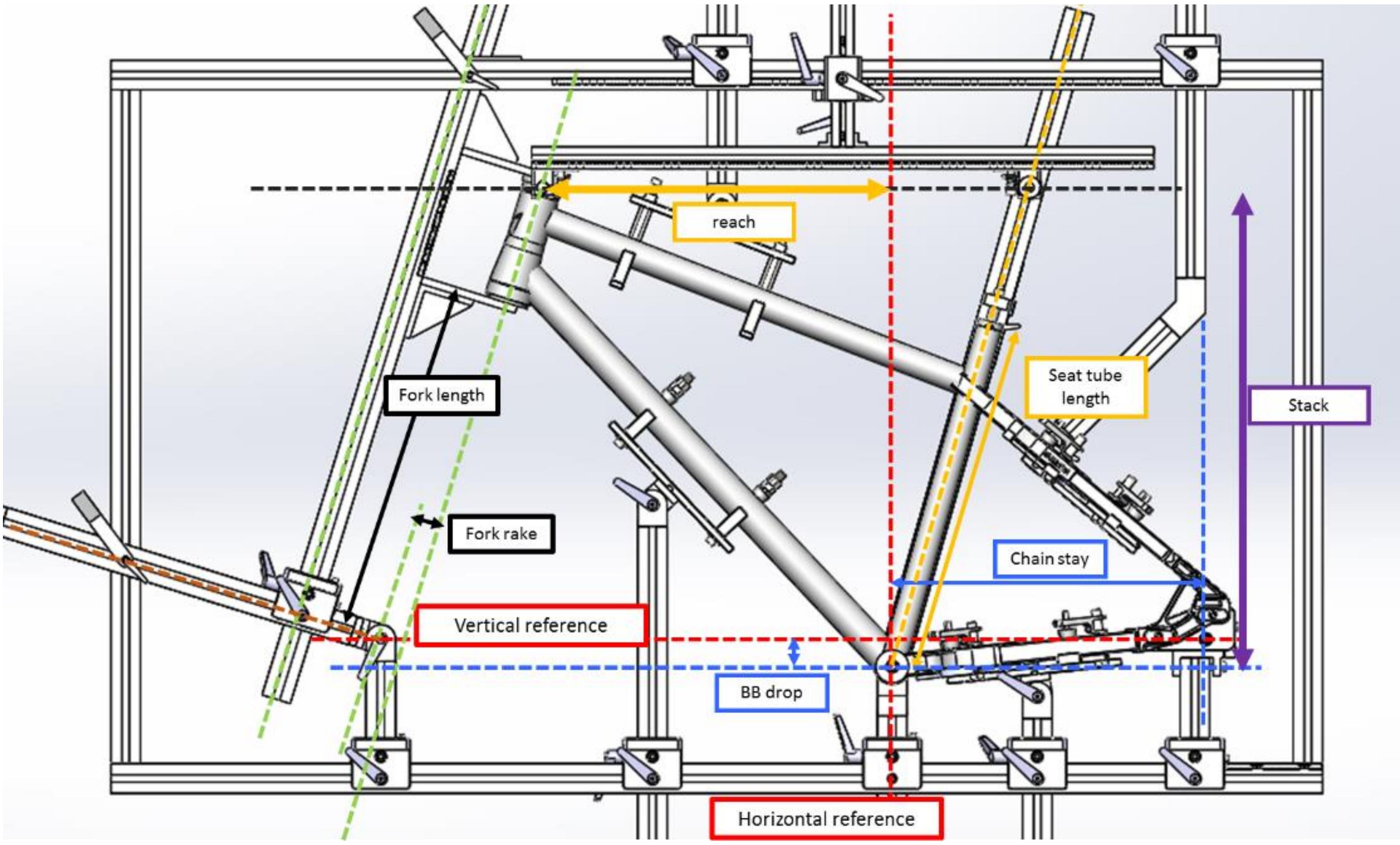


Figure 104: Details of geometrical parameters on new welding-jig design

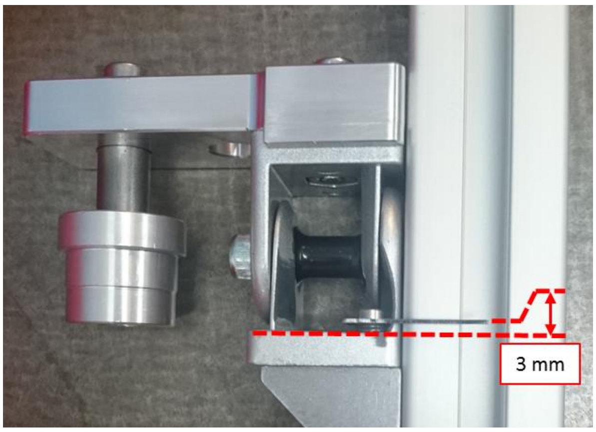


Figure 105:Spacers between measurement surface and needle that allow a correction of the ruler placement

4.6.1 Controlling main frame

The first calibration step is to ensure that the frame on which every components is located is actually straight and rectangular. To do so, a L shaped metal bracket calibrated by a third part is used to control the right angles. This calibration is also verified by measuring the diagonal of the frame.

4.6.2 Defining horizontal measurement reference

The horizontal reference is located on the welding jig with the purpose to ensure that the range of the reach and the chain stay length is sufficient. The location is made by using the right vertical profile of the frame as reference and the measure is made with a digital caliper. According to the CAD assembly, the horizontal measurement reference has to be placed at 550 mm from the right vertical profile.

4.6.3 Defining vertical reference

The vertical reference is made by the front and rear axles. Those axes have to be located on a horizontal line parallel to the bottom profile of the frame. The location of this bottom profile ensures that the bottom bracket drop range is according to the requirements. The distance bottom profile- front and rear axles is 170mm.

The calibration of this vertical reference is made using a digital height gauge by following the process described next:

- The front axis is fixed around the 170mm value and the height gauge is placed on the bottom profile of the welding jig.
- The location of the front axis becomes the zero of the height gauge (see Figure 106)
- The gauge is moved to the rear axis and the rear axis is moved until being coincident with the height gauge.
- The rear axis is then locked in its vertical translation position.

All the screws restraining the vertical translation of the front and rear axes are tightened and painted in red as to be not loosen.

Figure 106: Setting the vertical reference by placing the zero on the front wheel axle

4.6.4 Fork rake calibration

The fork rake measurement calibration is carried out on the welding jig by using a calibrated metal bracket, a height gauge and a long screw. The measurement principle is presented in the Figure 107.

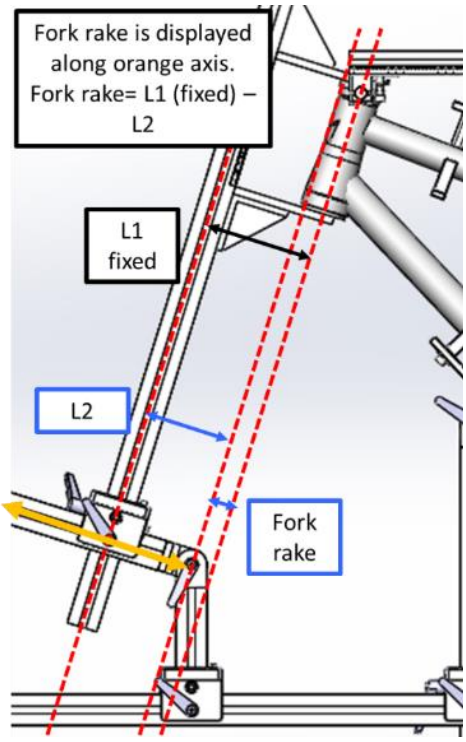


Figure 107: Fork rake measurement principle

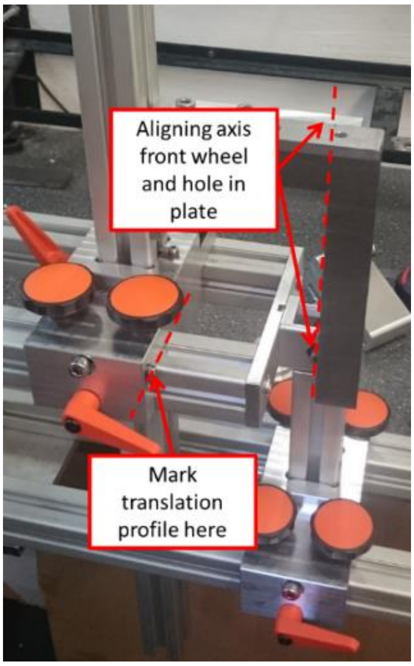


Figure 108: Calibration of the fork rake using a calibrated metal bracket

The process is described as follows:

- Ensure parallelism between fork rake axis and bottom profile with metal bracket and digital protractor.
- Place the metal bracket on the head tube holder plate and align the side of the bracket with the hole representing the head tube axis and with the center of the front wheel axis.
- Mark zero corresponding along the translation profile.
- Use the metal bracket to set the fork rake as a calibrated distance, in this case 30mm, and mark the translation profile once more (see Figure 108).
- Place the ruler on the translation profile according to the two marks and the rules of correction for the needle presented earlier.

4.6.5 Fork length calibration

The fork length measurement calibration is carried out on the welding jig by using a calibrated metal bracket and a height gauge. The process is described as follows:

- ensure parallelism between fork rake axis and bottom profile with metal bracket and control with height gauge that there is no variation of height along the axis.
- Place the height gauge on a metal block of known dimension to bring it closer to the front axis (see Figure 110).
- Set the zero of the height gauge at the front axis.
- To ensure that the range of fork length is respected, the head tube holder plate should be placed at 620mm

from the bottom of the translation profile (see Figure 109).

- Translate the head tube holder to 100mm above the front axis by measuring with the height gauge.
- Mark the translation profile on the top face of the translation block where the needle is.
- Repeat the two last operations with 220mm and 270mm.
- Place the ruler on the translation profile according to the three marks and the rules of correction for the needle presented earlier.

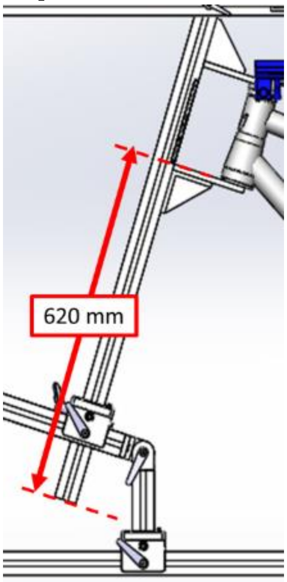


Figure 109: Locating the bottom of head tube for ensuring the required modulation range

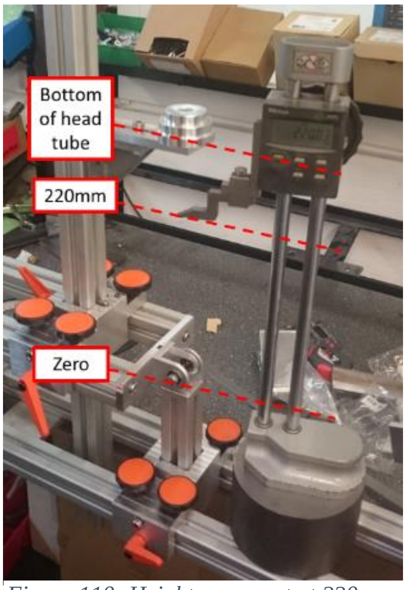


Figure 110: Height gauge set at 220mm, the bottom of the head tube must be aligned with the height gauge.

4.6.6 Seat tube length calibration

The seat tube length measurement calibration is carried out on the welding jig by using a calibrated metal bracket and a height gauge. The process is described as follows:

- Place the bottom bracket as its minimum height.
- Ensure the perpendicularity of the seat tube profile and the bottom profile with the calibrated metal bracket (see Figure 111).
- Place the height gauge on the bottom profile and set zero at bottom bracket axis.
- Mark the seat tube profile at different height with the comparator needle. In this case 50, 100 and 270mm (see Figure 113)
- Place the ruler on the translation profile according to the three marks and the rules of correction for the needle presented earlier (see Figure 112).

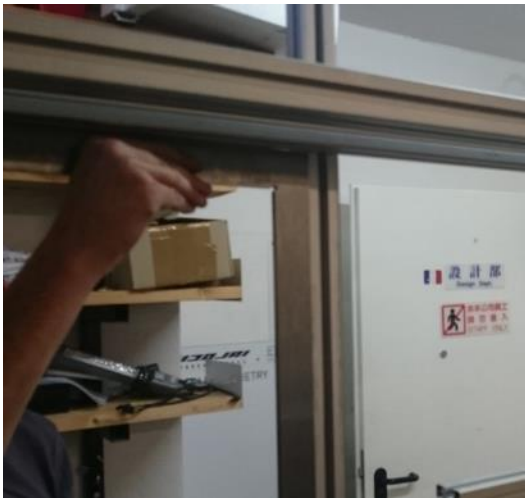


Figure 111: Metal bracket used for ensuring perpendicularity of the seat tube profile with the reference profile

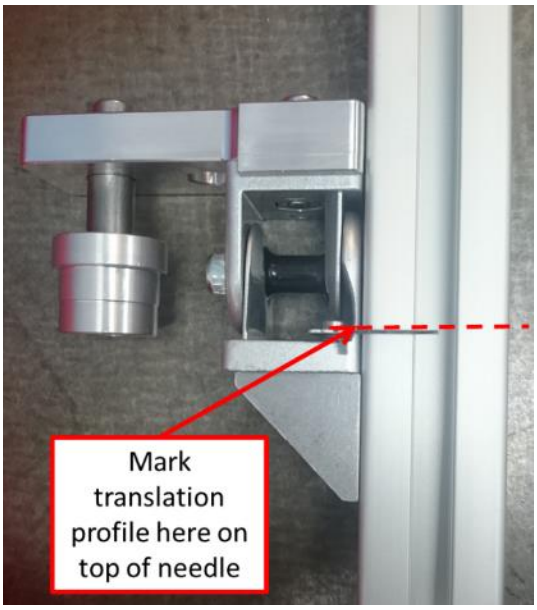


Figure 112: Description of where to mark the profile for positioning the ruler

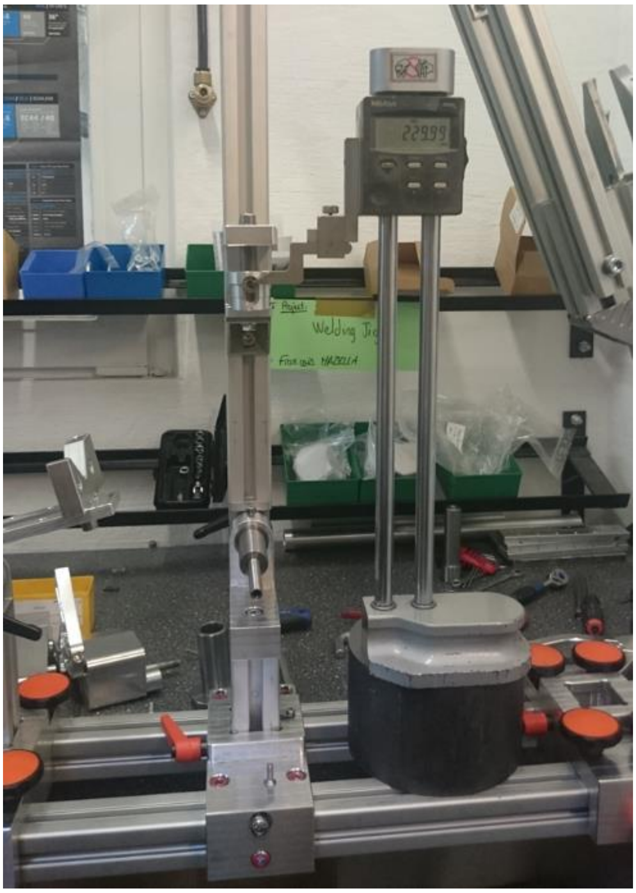


Figure 113: Aligning the screw of the seat tube interface with the height gauge.

4.6.7 Bottom bracket drop calibration

The Bottom bracket measurement calibration is carried out on the welding jig by using a calibrated metal bracket and a height gauge. The measurement principle is presented in the Figure 114.

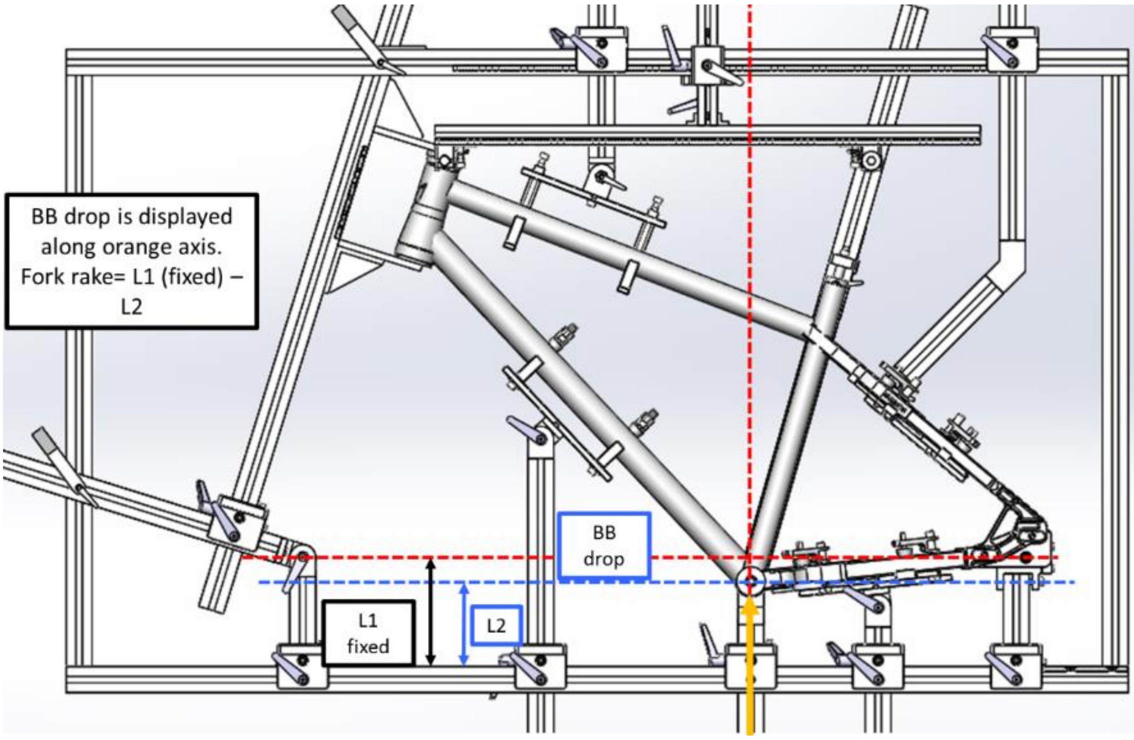


Figure 114 Bottom bracket drop measuring principle

The process is described as follows:

- Place the height gauge on the bottom profile and set the zero of the gauge on the front axis or rear axis.
- Set the height gauge at +40, +60, -40 and -60 mm and for each of those positions mark the translation profile (see Figure 115).
- Place the ruler on the translation profile according to the four marks and the rules of correction for the needle presented earlier.

Figure 115: Aligning bottom bracket axis with height gauge

4.6.8 Chain stay length calibration

The chain stay length measurement calibration is carried on the welding jig by using a calibrated digital caliper and an adaptor for the drop out. The process is described as follows:

- Place the bottom bracket drop at the zero value (aligned with front and rear axis).
- Assemble the adaptor in the drop out holder. The center thread represents the rear axis.
- Place a screw in the bottom bracket thread and make sure that the head of the screw is on the same plan than the outside of the drop out adaptor (see Figure 116).
- Place the rear axis at several distance from the bottom bracket: 300mm, 400mm, 500mm and mark the bottom profile at each of this position. The mark should be located on the right side of the translation block.
- Place the ruler on the bottom profile according to the three marks and the rules of correction for the needle presented earlier.

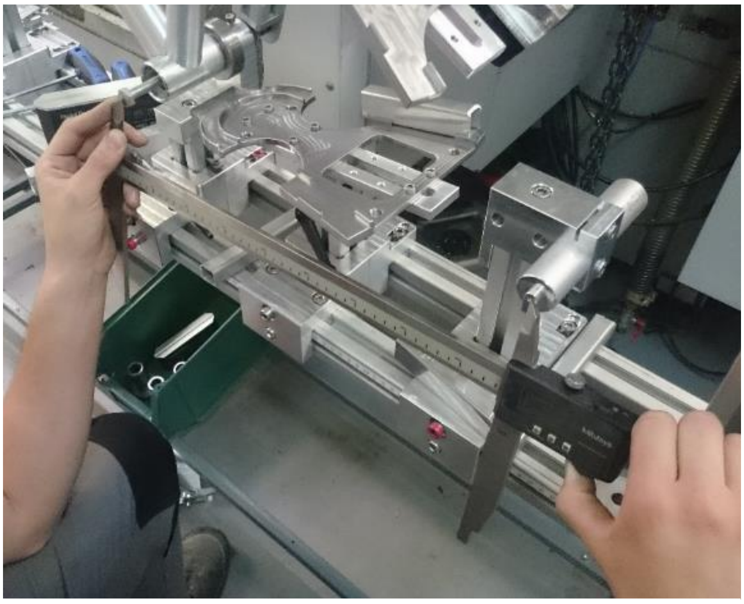


Figure 116: Calibrating chain stay length with caliper

4.6.9 Reach calibration

The reach measurement calibration is carried out on the welding jig by using a calibrated digital caliper and a

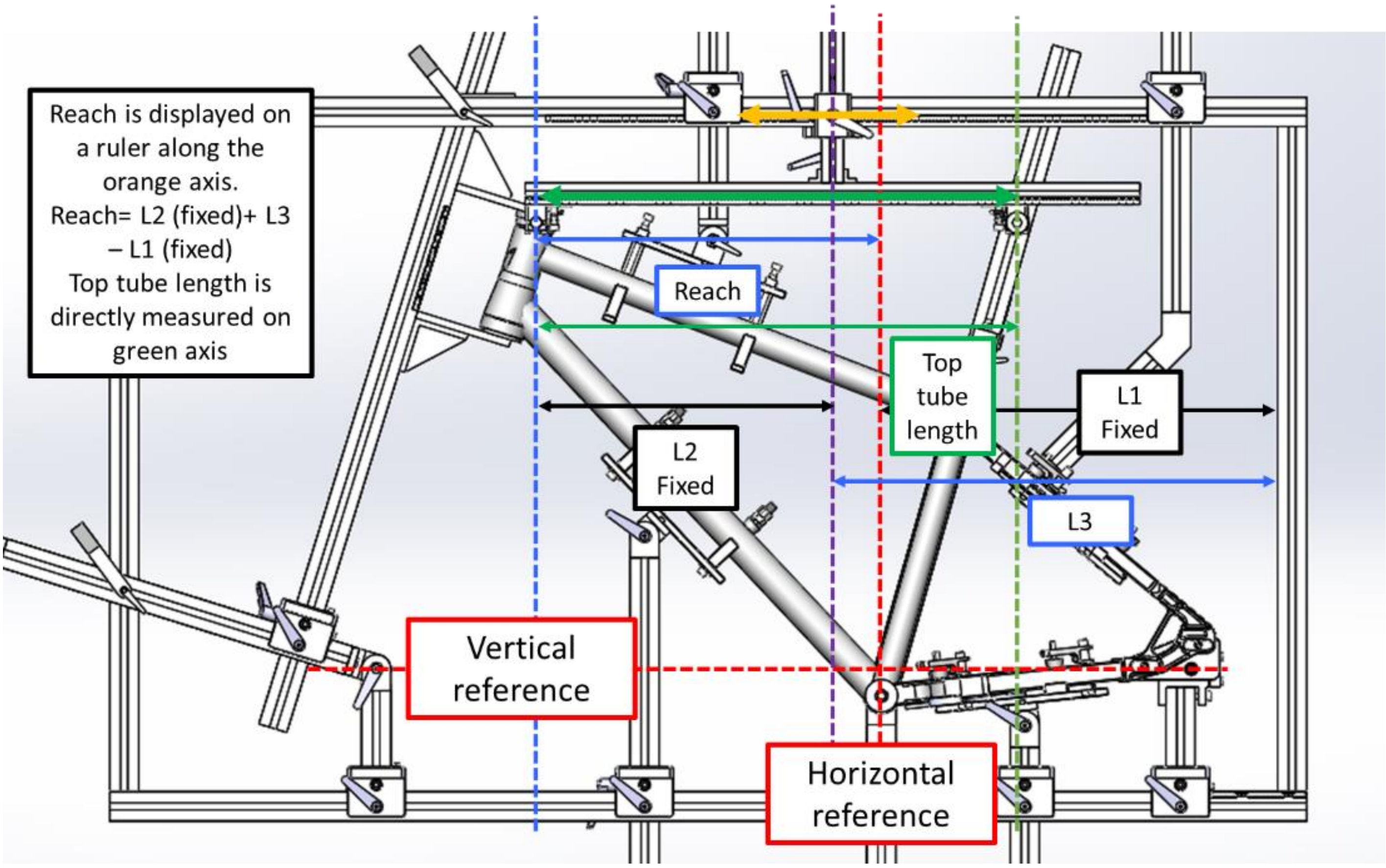


Figure 117: Details of reach measurement principle

calibrated bracket. The measurement principle is presented in the Figure 117.

This measurement being critical, the calibration is being carried out by two different methods that control each other.

4.6.9.1 Calibration with metal bracket

A calibrated metal bracket with a right angle and dimensions of 300x600mm is used for this method. The process can be described as following:

- Translate the reach measurement system as its lowest height.
- Place a screw in the bottom bracket thread and ensure that the head of the screw is in the same plane as the inner face of the horizontal profile for the reach measurement.
- Align the metal bracket with the top of the horizontal profile for the reach measurement. For the first measurement, align the 300mm side and for the second, align the 600mm one.
- Place the metal bracket as its sides are aligned with the laser center and the bottom bracket axis (see Figure 118).

- For the two position of the bracket, mark the position of the translation block for the reach on the top profile of the jig (see Figure 119).

Figure 118: Calibration using a calibrated metal bracket

Figure 119: Details of where to mark the translation unit for the measurement system

4.6.9.2 Calibration with caliper and steel ruler

A digital caliper and a steel ruler are used for this method. The process can be described as following:

- Measure with the steel ruler the distance from the bottom bracket axis to the left vertical profile of the frame jig. According to the calibration of the horizontal reference, this dimension should be 1027 mm (see Figure 121).
- Using the steel rule and a metal bracket, set the laser center at 727mm from the left vertical profile of the jig. This would set a reach of 300mm (see Figure 120).
- Mark the position of the translation block for the reach and compare with the first method.
- Place the ruler on the bottom profile according to the three marks and the rules of correction for the needle presented earlier.

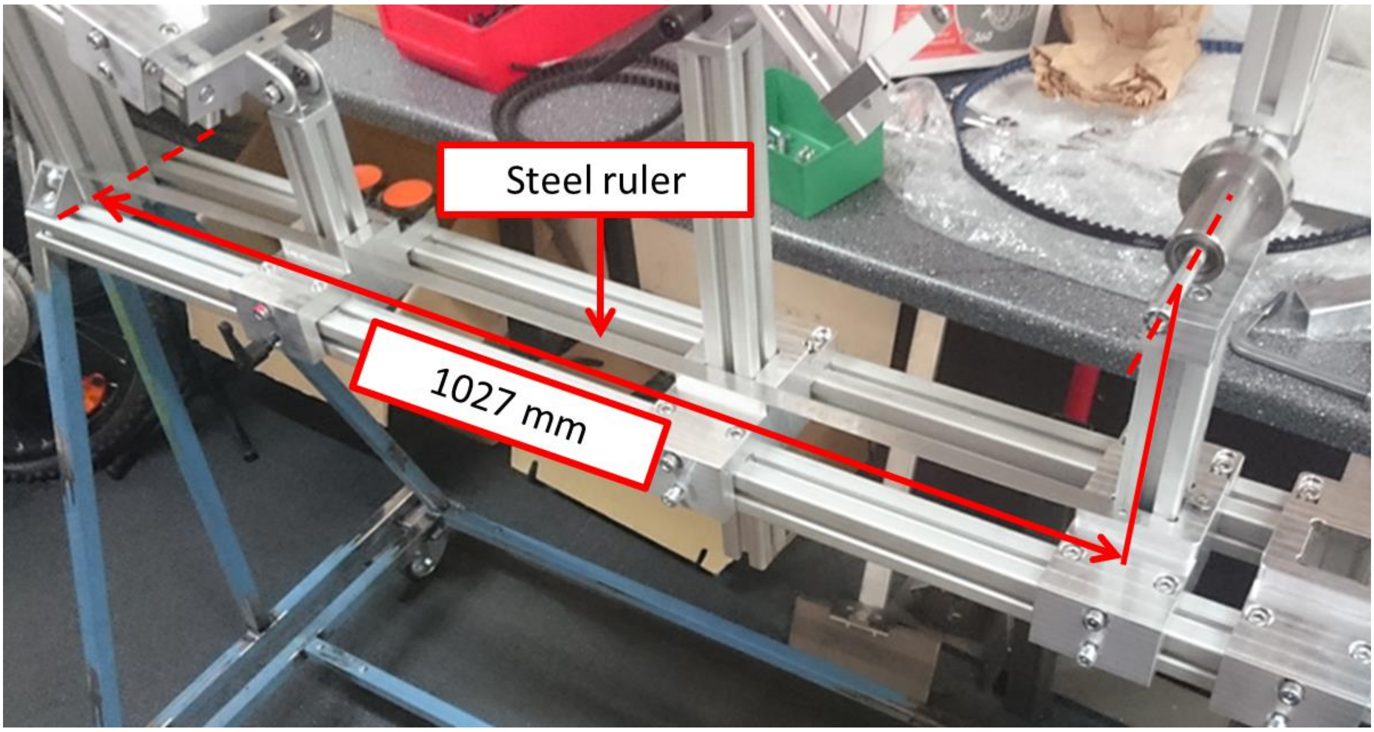


Figure 121: Controlling horizontal distance between bottom bracket and left vertical profile

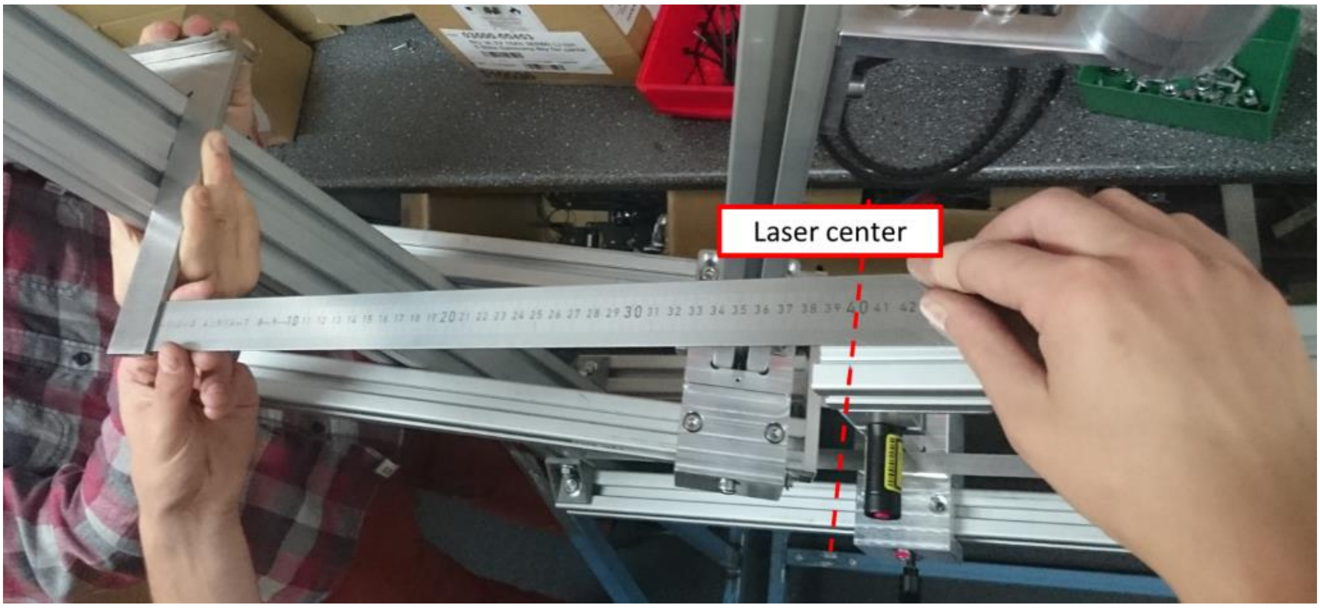


Figure 120: Setting the appropriate reach using a metal bracket and steel rule

4.6.10 Stack calibration

The stack measurement calibration is carried on the welding jig by using a height gauge and a calibrated bracket.

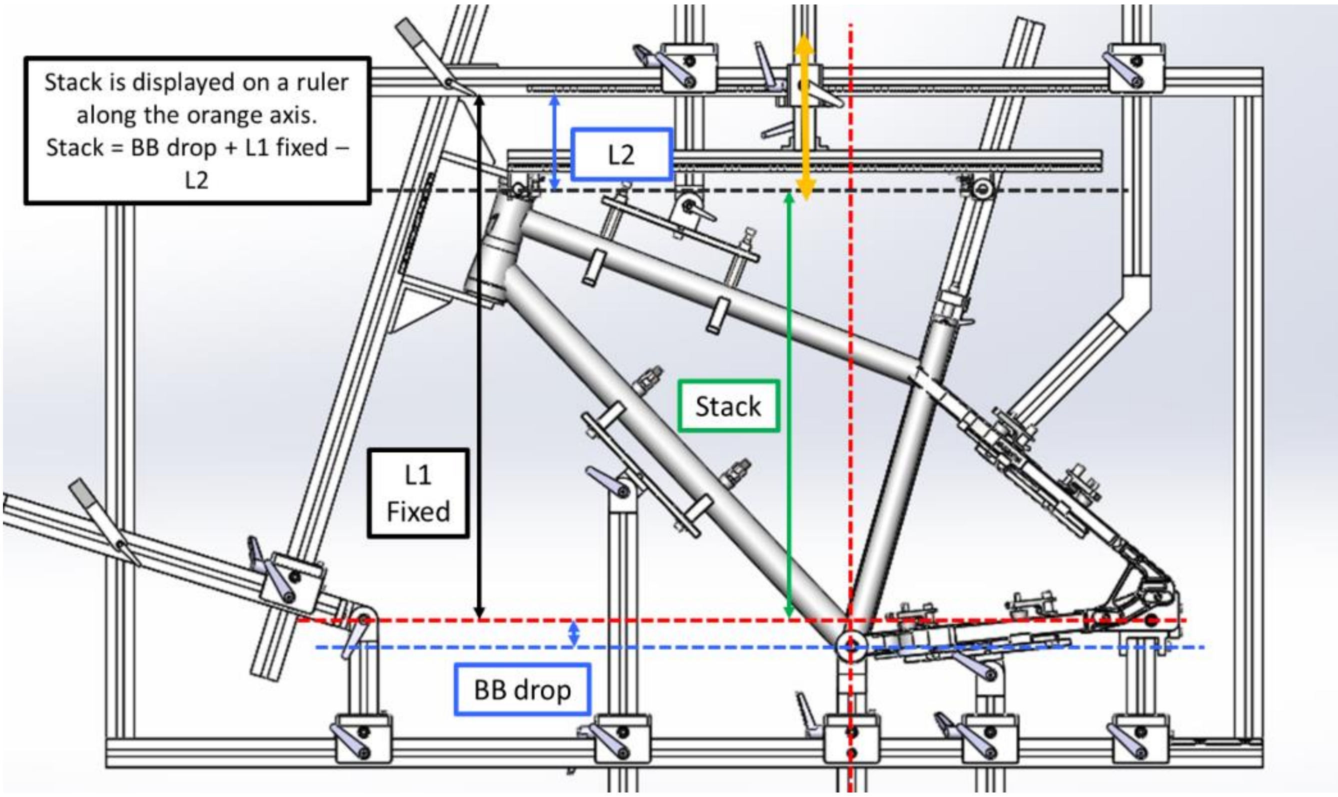


Figure 122: Stack measurement principle

The measurement principle is presented in the Figure 122.

The stack has already been defined by the combination of the fork rake, fork length, head tube length and head tube angle. Therefore, this measurement is displayed for control purpose. We can therefore afford to calibrate the stack by using other calibrated measurements such as the seat tube length or bottom bracket height. The stack being composed by two variable dimensions; it is necessary to set one of them to zero in order to calibrate the other. The bottom bracket drop is already calibrated, then the process can be described as following:

- Set the bottom bracket drop to zero using the height gauge and the front or rear axis as reference.
- Ensure the perpendicularity of the seat tube profile and the bottom profile of the welding-jig frame via the calibrated metal bracket.
- Translate the reach translation block so the laser used for the reach is aligned with the center of the seat tube axis.
- Place the seat tube holder unit at fixed positions (500mm, 400mm and 300mm) and for each of this position align the laser with the top of the seat tube (see Figure 123).
- Mark the stack vertical translation profile for each of the three positions.
- Place the ruler on the bottom profile according to the three marks and the rules of correction for the needle presented earlier.

Figure 123: Aligning laser with top of the seat tube

Figure 124: Details on where to mark the translation profile for the stack ruler

4.6.11 Top tube length calibration

The top tube length measurement calibration is carried out on the welding jig by using a steel ruler. The measurement principle is described in the Figure 117. The calibration process is carried as following:

- Set up the steel ruler to a set of values (400mm, 500mm and 600mm).
- Mark the horizontal profile for the top tube length at the values described above. Make sure that the reference of the caliper is the center line of the reach laser (see Figure 125).

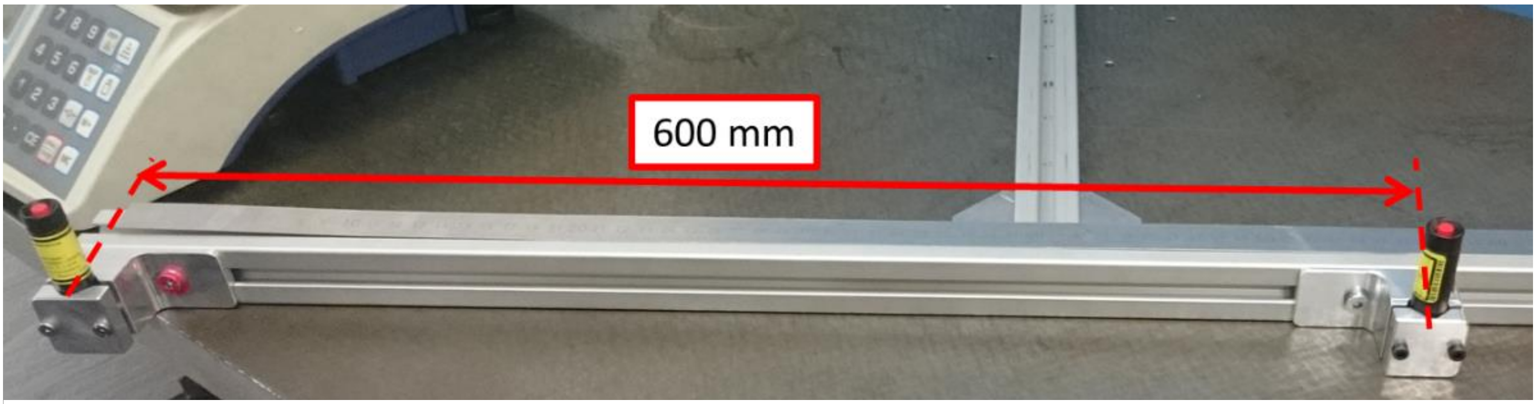


Figure 125: Calibrating top tube length with steel rule

4.7 Test and welding of a frame

Once the welding-jig has been calibrated, the design of the jig has been tested by assembling and tacking a hardtail frame. This process reveals the possible flaws in the design and is necessary in order to provide the technician with an efficient and easy setting working tool. During this section, we will describe the setting steps of the welding jig, we will then describe the problems encountered and finally present the modifications carried out on the design.

4.7.1 Setting steps of the welding-jig

The Setting process of the jig needs to be achieved in a certain order to ensure the geometry of the frame as well as reducing its cycle time. Indeed, the setting of the welding jig can be divided in three sub-processes. The different steps are summarized in Figure 126, however, a description is provided for each sub-process.

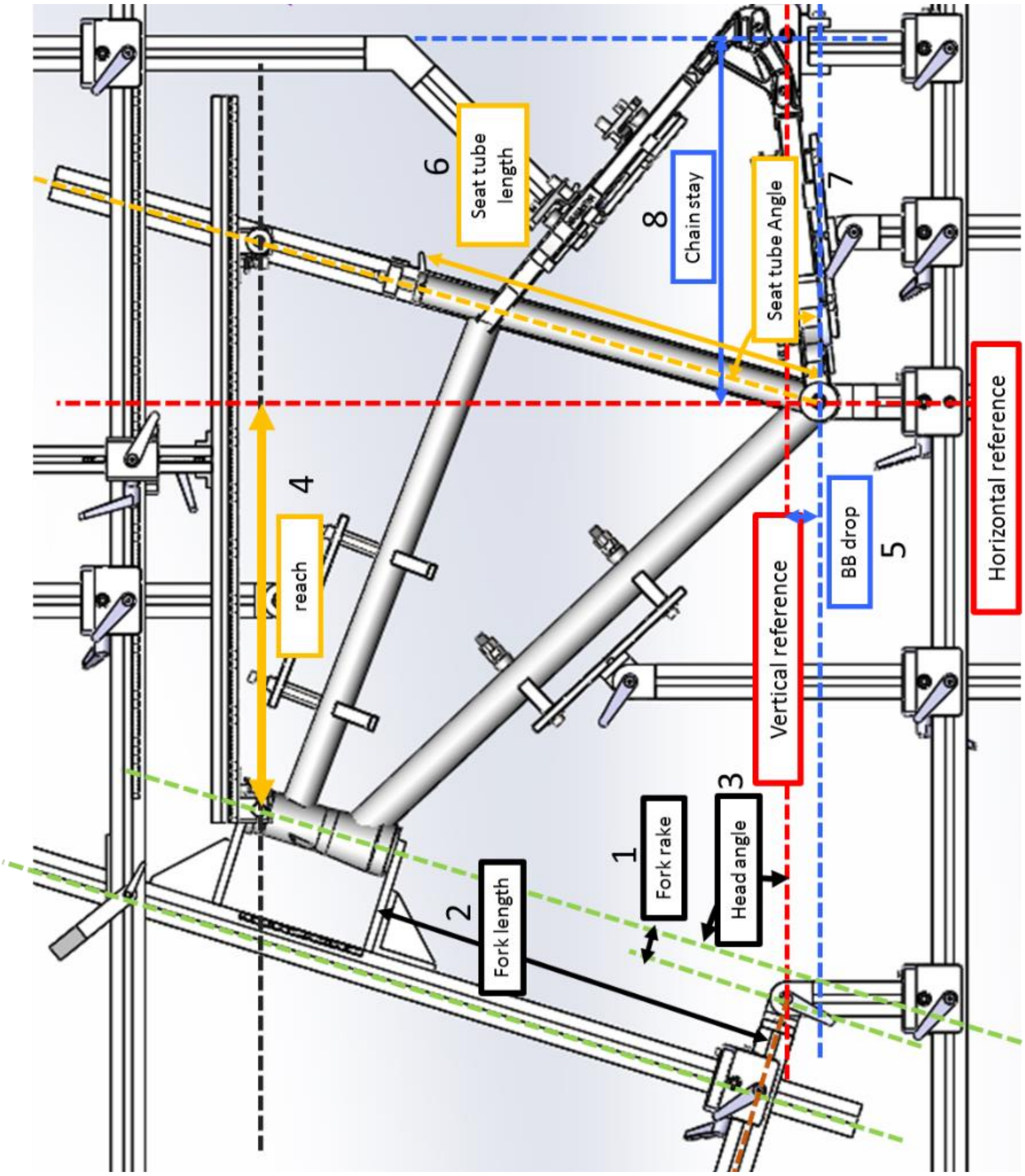


Figure 126: Setting order for the parameters of the new welding-jig

- Setting of the head tube

The setting of the head tube includes the definition of the following parameters:

- Fork rake
- Fork length
- Head angle
- Reach

In order to set up those parameters correctly it is recommended to set them in the order presented above. Indeed, the modification of the fork rake and fork length could disturb the setting of the head angle and so should be defined before. Finally, the reach can be easily set by translating the front unit along the bottom profile without disturbing the other parameters whereas any change in the fork rake, fork length or head angle will modify the reach.

  - Setting of seat tube

The setting of the seat tube is carried out in the following order:

- Bottom bracket drop (or height)
- Seat tube length
- Seat tube angle

Indeed, the seat tube profile being long, the pivot joint cannot be locked strongly enough to ensure alone the complete conservation of the seat tube angle. Therefore, a clamp is place at the junction of the seat tube angle with the top horizontal profile of the welding-jig frame. To avoid having to position this clamp many times, the seat tube angle is set as the last parameter.

When the head tube and seat tube are in place, the front triangle of the frame can be cut and placed in the jig, this process has been already described in a previous section.

  - Setting of the rear triangle

The setting of the rear triangle is made by first setting the chain stays length and then aligning the seat stays and chain stays to the front triangle tubes.

4.7.2 Problems encountered and modifications

The test of the welding jig can be divided in four steps: the setting, the mitering of the tubes and positioning, the tacking and the removal of the frame from the jig. While the tacking process did not reveal any problem in the design, some difficulties were experienced in the other process. We will go through each problem encountered and the modifications made to solve them.

  - Setting of seat stays position.

The major problem encountered on the welding jig was the setting process of the yoke and seat stays on the rear triangle. Indeed, on the current design, the position of the yoke and the seat stays is defined by a machined plate presented in Figure 128. This machined plate does not allow any variation of relative position between the yoke and seat stays. This particularity combined with the design of the motion unit for this machined plate on two translation axis and one pivot (see Figure 127) make the finding of the right position of the machined plate extremely difficult for the technician. Moreover, the length of the translation profile made the system less rigid and therefore the alignment between drop-outs, seat tube and seat-stays was not respected.

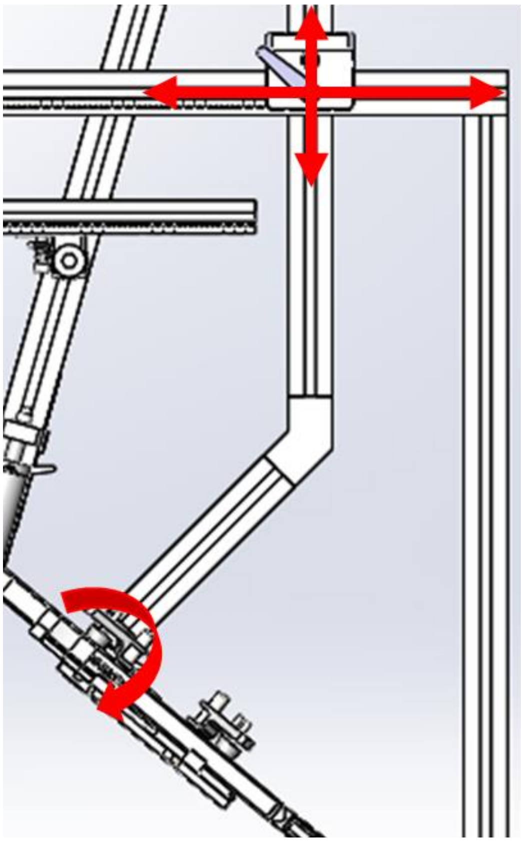


Figure 127: Three different motions required for the setting of the yoke and seat stays

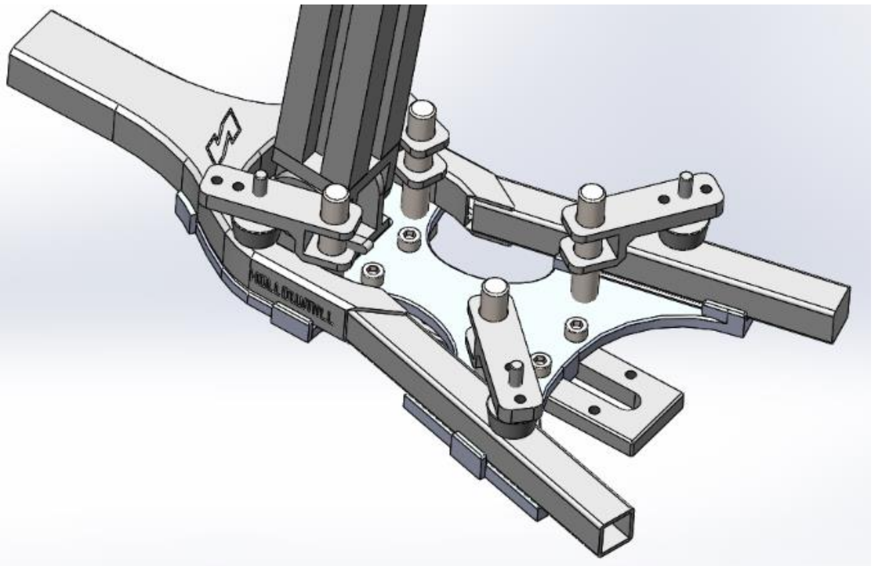


Figure 128: Plate holding the seat stays and yoke

To solve this problem, the complete seat stays holder system has been re-designed. The new design presented in the Figure 129 answers all the difficulties and reduces considerable the setting time for the seat stays. The setting of the yoke and seat stays positions relies on the principle presented in the Figure 131. Indeed, between two different sizes of frames, the chain stays and drop-outs are not displaced. Only the seat stays and yoke will rotate around their junction with the drop-out and meet the seat tube in front of the down tube.

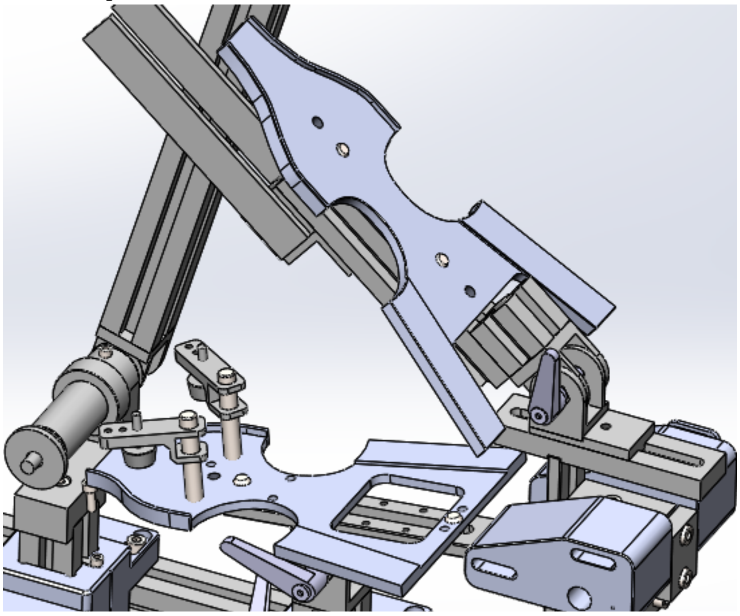


Figure 129: New design for the yoke and seat stays positioning and holding

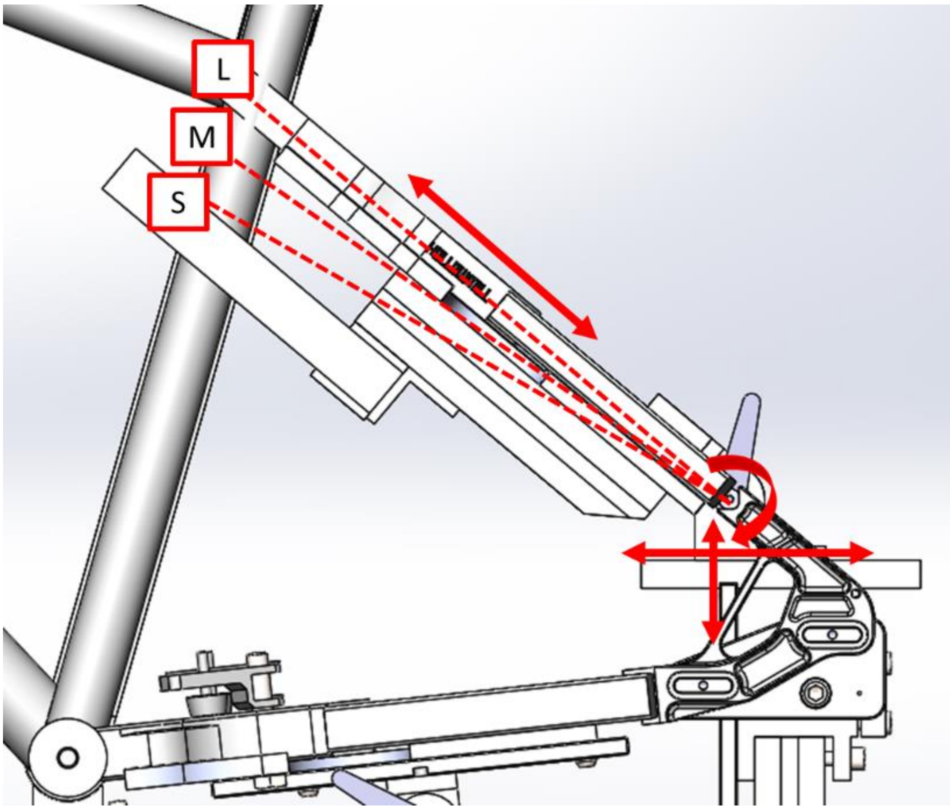


Figure 131: Principle of motions for the new design of yoke and seat stays holder

This new design allows the seat stays and yoke holding plate to rotate around the junction with the drop outs. When the center of rotation of the plate is locked, this holding plate can translate on the profile to adjust the position of the yoke and seat stays. Two aluminum plates ensure the centering of the assembly by clamping around the seat tube. This new design has been manufactured using the same machines as described earlier and is shown in the Figure 130.

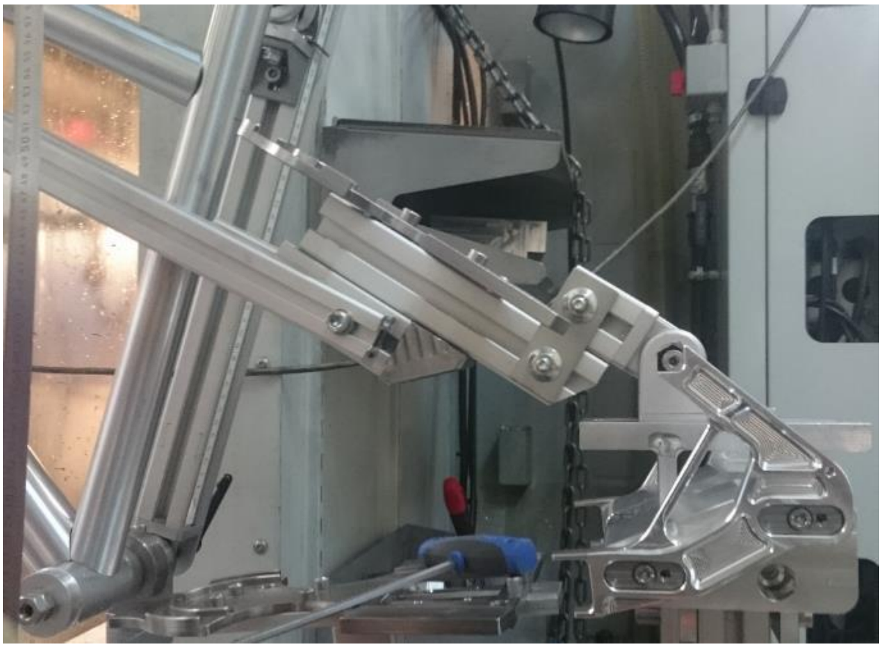


Figure 130: Manufactured new design without yoke and seat stays

- Positioning of Yoke and Hoof

The main problem encountered while positioning the tubes was the impossibility to place and remove easily the yoke and hoof on their respective fixture from the back because of the locating walls on the inside of the profile, see Figure 132. Those walls have therefore been removed and the outside walls have been made longer to still ensure the good positioning of the parts. Thus, the yoke and hoof can be slide from the back of the plate around the bottom bracket or the seat tube. The final design is presented in the Figure 133.

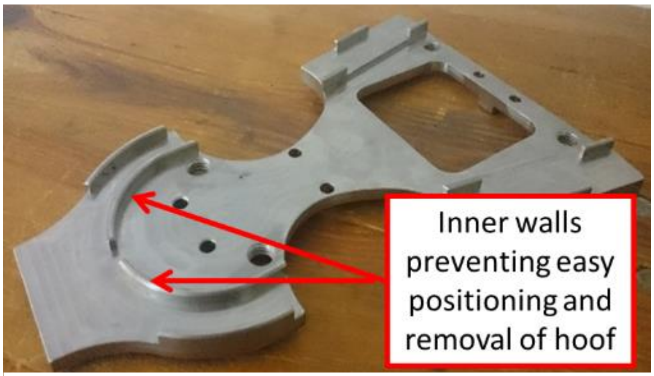


Figure 132: Description of problem occurring on current holding plate for yoke and hoof

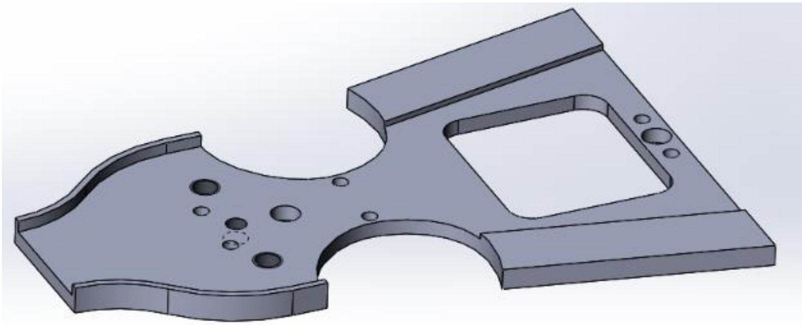


Figure 133: New design of holding plate with longer guidance for the hoof or yoke and removed inner walls

- Removal of the frame after tacking

Once the frame has been tacked, the frame is removed from the welding jig. During the removal of the frame, the interfaces have to be unlocked to easily release the frame. On the first design presented, the removal required to un-set the head tube position, the seat tube length and the seat stays positioning in order to rotate the frame around the bottom bracket to remove the frame. This problem was mainly due to the fact that the bottom bracket axis was fixed and blocking any translation in the plane of the welding jig. If the un-setting of the parameters is not a problem in the production of tailor-made frames because each frame is different from another, this could become a problem in the production of a batch of frame identical to each other. Indeed, the technicians would have to set the parameters of the jig every time and thus increasing the risk of dispersion between the geometrical parameters of two frames supposedly identical.

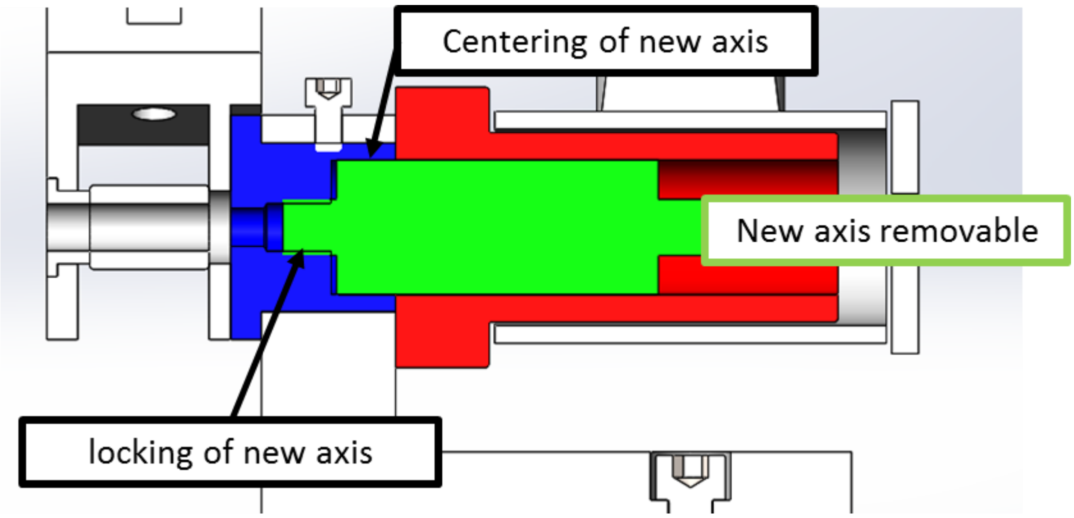


Figure 134: New design for bottom bracket interface with axis removable

To solve this problem, the Bottom bracket axis supporting the adaptor for each standard has been made removable following the design presented in Figure 134.
The final welding-jig design with all the new modifications is presented in Figure 135 with a frame ready to be tacked positioned in it.
The tacking and removal of the frame has been greatly improved by these modifications. The technician in charge of the mitering of the tubes and the welder are satisfied with the jig. The first aligning of the frame before the heat treatment process showed that the deformation of the frame due to the welding process is similar after the complete welding of the frame on the new jig as after two aligning processes with the current manufacturing process.
A rolling stand has been manufactured to hold the welding jig and roll it around the workshop for an easy access for the technicians and the welders. Finally, the setting of each parameter has been made easier by using star-grip screws and levers while the relative motions fixed during the calibration have their setting screws marked in red and taped to avoid modifications.

Figure 135: Final welding-jig with an Argon GLF frame ready to be tacked

5 Conclusion and discussion

5.1 Project conclusion

This project outlined the importance of the frame geometry in a bicycle handling behavior and described the influence of each of the geometrical parameters on it. This project also reviewed and analyzed the current welding-jigs on the market for tailor-made production of bicycle frame. Then, the complete process of design, manufacturing, calibrating and testing of the new Nicolai GmBH tailor-made welding jig has been described. The welding jig designed and manufactured during this project fulfills all the requirement expressed by Mr. Nicolai. Indeed, this jig is unique by its ability to display every geometrical parameter of a bicycle frame. Furthermore, it is adaptable to a broad range of frame sizes, it locates and holds in position all the components of a hardtail frame, reduces the number of aligning process and is easily movable around the workshop. The technicians to be working with the new welding-jig have been informed and trained regarding its setting and also its calibration process. The knowledge on welding-jig acquired during this project has been documented and shared with the engineers in charge of the tailor-made design. Finally, all the Nicolai GmBH staff is pleased with the results of this project and has expressed their satisfaction.

5.2 Project discussion and reflections

The project carried during those 6 months at Nicolai GmBH was interesting owe to its multidisciplinary character. Indeed, the literature review on bicycle geometry and the creation of a customer form dealt with knowledge and data acquisition and structuring. Another aspect was that the design of the new tailor-made welding jig required a mechanical design knowledge to ensure the good kinematic motion between parts and avoid over constrained mechanisms. The design also required a deep knowledge in manufacturing processes. Indeed, it has been necessary to design all the parts keeping in mind the tools and machines available for the machining, thus simplifying the operations management for the technicians. This aspect of the work has been particularly interesting and important for the success of the project because the machines and technicians were rarely available and therefore more involved in the manufacturing of the parts when those parts had been designed around the manufacturing process. Moreover, the calibrating of the jig required knowledge in metrology while the assembly of the welding-jig and the mistake-proofing of the setting referred to lean manufacturing.

This project has been motivating and inspiring because it has been a complete project from the birth of the idea of a new welding-jig from Mr. Nicolai to the tacking of a bicycle frame on the manufactured welding-jig. A period of six months is a short time for such an important project and that represented the main source of motivation: the possibility to carry out completely a project from concept to life. If this represented a motivation, it was also a source of stress and pressure. Indeed, it has been decisive to listen to the technicians in order to sort the pros and cons of the former welding-jig, to understand the process of positioning the tubes for finally quickly proposing a design to Mr. Nicolai and start the production of the parts in time. Listening to the technicians, the welders, and Mr. Nicolai involved high communication and managerial skills in order to come out with a solution that suits the needs of everyone. In addition to managing the project in house at Nicolai GmBH, most of the components had to be bought from suppliers and having the responsibility to deal with all of them was an extra task to be carried along, but highly formative.

Regarding the design of the jig, the choice of using aluminum extruded profiles and standard pivot joints brought the possibility to construct easily complex systems but also brought an uncertainty in the alignment of the different elements as the pivot joints were not rigid enough and needed reinforcement. Moreover, the laser measuring system could be redesigned to improve its stiffness and its calibration process.

During the design and manufacturing periods of the project, Mr. Nicolai pushed me to start the production of some components in order to try their functionality and correct them if some mistakes were revealed. This working process of learning by doing wrong is educational and allows to fully understand the problems occurring. It also brings dynamics to the project because there is no long period of time when the manufacturing of the project is not progressing. However, if some components needed to be redesigned or were simply put aside for a better solution, the manufacturing processes had to be carried out again thus increasing the workload on the technicians and machines. This particular aspect had been a real problem in the project manufacturing. Indeed, the CAD files and documents needed for the manufacturing of all the parts regarding the rear triangle interfaces had been given to the technicians two months and a half before the end of the master thesis agreement, but the parts have been manufactured only two weeks before departure even though weekly reminders had been given. This lead to extremely intensive work hours the last two weeks in order to carry all modifications needed.

Finally, Mr. Nicolai and all the staff at Nicolai GmBH are satisfied with the welding-jig, the training of the employees and all the deliverables.

Appendices

Appendix 1: Description of the different mountain bike disciplines.

Cross-country (XC):

Cross country is the most common discipline of mountain biking and the only one represented at the Olympic games. In cross-country, the rider tries to achieve a loop in the shortest time possible. The trails are most of the time composed of fire roads or single tracks that can be technical but the difficulty in cross-country lies in the number of steep climbs and the average speed along the track. A cross country mountain bike is therefore shaped for speed and pedaling efficiency more than for providing support in technical terrains.

Downhill (DH):

Downhill mountain biking is the extreme sport in mountain biking. The rider's goal is to achieve a very technical track with jumps and rough terrains in the shortest time possible. However, the track is only going downhill and the climbing can be done using a chair lift or a shuttling service. Downhill mountain bikes are made for being resistant to any kind of extreme solicitations as well as being light enough to be moved easily by the rider, they also provide the rider with big suspensions for technical section and powerful brakes.

Enduro:

Enduro mountain-biking can be described as being the mix between cross country and downhill riding. The main goal of the rider is to be able to pedal to the top of the mountain with a sufficient pedaling efficiency and going downhill as fast as possible on track sometimes similar at downhill tracks.

Dirt jumping:

Dirt jumping is a mountain bike discipline where the rider goals is to have fun jumping in the air. The jumps are usually shaped by the riders themselves on flat ground or slightly descending slopes. The ability of a rider is judge by its capacity of doing tricks in the air or jumping big jumps. A dirt-jumping mountain bike is aimed at being easily movable in the air as well as being extremely responsive to the movement of the rider on it. For those reasons, a dirt-jumping mountain bike is most of the time without rear suspension and smaller than any other mountain bike.

Appendix 2: Description of a mountain bike and its components

Figure 1: Description of a mountain bike and its components

Appendix 3 : Interviews of Chris Porter and Jack Reading

Interview with Chris Porter from Mojo Suspension:

<u>Francois.Mazella:</u> *Chris, I have seen that you are currently riding a tailor made Nicolai Ion 16. I am for myself riding the production version of your previous tailor made frame design in 2014.* (Note: The Nicolai Geometron, Bike discussed about in the article on www.mbr.co.uk) *Could you tell me if there is any difference between those two model?*

<u>Chris.Porter:</u> *Yes, of course. I have been a bit further on slackening the head angle. Today I am riding a Fox 40* (Note: Double crown fork normally used on downhill bikes) *to feel more comfortable with the steepness of the track and that brings me to 61.5° of head angle compared to your 63.5°. I am also riding now a longer chain stays of 460mm.*

<u>F.M:</u> *This is my first ride on a bike of that size, following the "lower, longer, slacker" geometry, and I directly felt the difference in the handling and stability of the bike. It seems to require a certain commitment to make it fast, can you share your experience about that?*

<u>C.P:</u> *First you have to understand that you have not been riding a bike fitting you before and it takes some times to switch to a neutral position on this bike but the key is to not be afraid of riding aggressively. The lower front end and the slacker head angle removes weight on the front wheel, so to keep the traction on the front tire, you do need to lean forward and use more your upper body than you used too. This is not a bike to ride slowly with!*

<u>F.M:</u> *I have had the time to try on a quick up hill and was surprised by its climbing abilities. Could you explain me where does this bike is different from other?*

<u>C.P:</u> *Most of mountain bikes have seat tube angle too slack*. (Note: A seat tube is considered as slack below 72°) *By this I mean that on an actual mountain bike, the center of gravity of the rider is too close to the rear axle and creates this feeling of a twitchy steering. The Nicolai bike we ride has a seat angle of 77° and the saddle is pushed to the front in order to increase the traction on the front wheel. Finally, with a longer chain stay, we increase even more this stability in climbing.*

Interview with Jack reading from the team OneVision Global Racing:

<u>Francois Mazella</u>: *Jack, you and your team of four riders have been riding for two months the new Nicolai downhill bike, the Ion G19. How did the switch from your previous bike to the Nicolai go and what convinced you that the geometry was right?*

<u>Jack Reading:</u> *That was pretty straight forward, I had the opportunity to try a Nicolai Geometron at a test event from Nicolai in the Forest of Dean during this winter and at this time I was looking for a new bike frame sponsor for the One Vision Global racing team* (Note: As well as being the top rider of the team, Jack runs the team with the help of his father Phil Reading). *I knew well Chris Porter because he had been sponsoring us with suspension for several years and he convinced me to take the Nicolai Geometron with me for some time to try the geometry. After several laps I felt quickly at home on the bike and I was going faster every time until one moment I was just few seconds slower with the Geometron than with my Trek Downhill bike* (Note: The Nicolai Geometron is an enduro bike with 160mm of rear wheel travel, normally not designed to stand the roughness and speed of a proper Downhill track at the pace of a Professional rider). *I called Chris Porter and we got in touch with the engineers of*

Nicolai in order to design a prototype of a Downhill bike for the World Cup season. After some time fine-tuning the numbers on the geometry, we received from Nicolai the four downhill bikes for the team at the beginning of February 2016.

F.M.: *Did the Nicolai downhill bike fulfilled your expectations? And what changes did you have to make on your riding style?*

J.R.: *At first, when you sit on the bike, the first things that comes to your mind is: "That is too long, I will never be able to make it turn fast enough". But when you start riding it, you just feel that it is not this bike that is too long, but all your previous bike that have been too short. It is not possible for me now to go back to a normal sized bike, I feel like I am going to go over the bar as soon as the track is going steep or when you hit a compression. It is true, you have to push it more if you want it to turn quickly, but it is made easier by the fact that the long front triangle forces you to be leant forward and so forces you to be more aggressive in your style of riding. I feel myself trying to get more speed at some part of the track where I was braking before, my previous bike was not stable enough and was bringing me out of the track. The downside is that you are using more you core muscle and your upper body that on a normal bike, therefore you might get tired more quickly on a long track and loose concentration. But if you train hard enough and hit the gym accordingly, you will definitely be faster on this geometry. For my part and I think I can talk on behalf of the other riders, we have never felt so confident in an off-season* (Note: the downhill World cup season started on the 9th of April in Lourdes, France and finishes on the 11th of September in Val di Sole, Italia).

Appendix 4: Description of 17-4 PH steel

"AK Steel 17-4 PH® is a martensitic precipitation-hardening stainless steel that provides an outstanding combination of high strength, good corrosion resistance, good mechanical properties at temperatures up to 600°F (316°C), good toughness in both base metal and welds, and short time, low-temperature heat treatments that minimize warpage and scaling. This versatile material is widely used in the aerospace, chemical, petrochemical, food processing, paper and general metalworking industries."[29]

COMPOSITION

	%
Carbon	0.07 max.
Manganese	1.00 max.
Phosphorus	0.040 max.
Sulfur	0.030 max.
Silicon	1.00 max.
Chromium	15.00 - 17.50
Nickel	3.00 - 5.00
Copper	3.00 - 5.00
Columbium plus Tantalum	0.15 - 0.45

Figure 136: Composition of 17-4 PH steel
Source AK Steel

[29] Source :AK Steel, *17-4 PH steel product data sheet*, Downloaded the 04/08/2016 at: http://www.aksteel.com/pdf/markets_products/stainless/precipitation/17-4_ph_data_sheet.pdf

Appendix 5: Composition of 7005 aluminum alloy

Element	Content (%)
Aluminum, Al	93.3
Zn	4.5
Magnesium, Mg	1.4
Manganese, Mn	0.45
Zirconium, Zr	0.14
Chromium, Cr	0.13
Titanium, Ti	0.04

Figure 137: Composition of 7005 aluminum alloy
Source: Azom.com

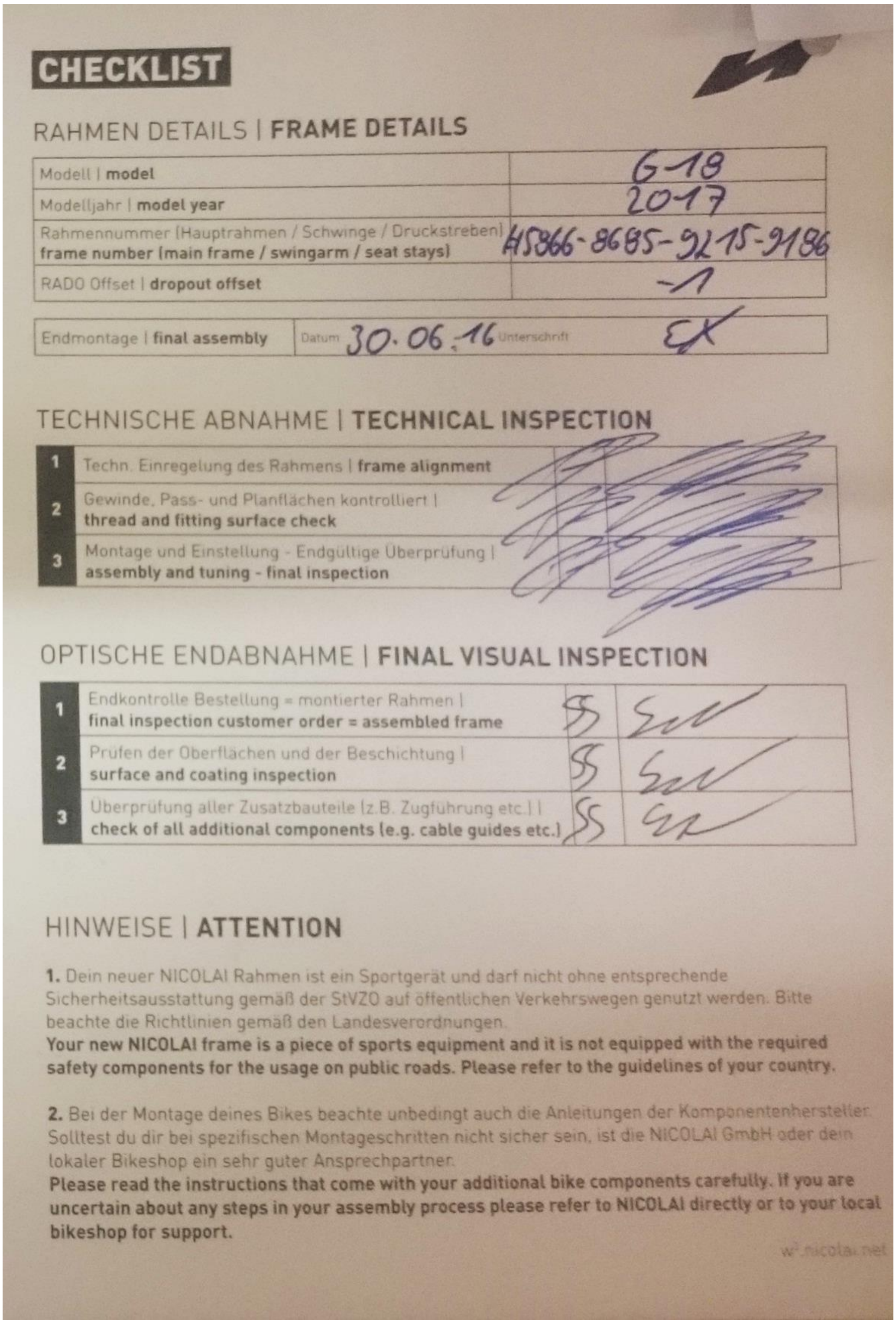
Appendix 6: Description of metal filler used in the welding of the Nicolai Frames

Composition Specification (%) (single values are maxima except as noted)

Alloy	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Others	
									Each	Total
5083	0.40	0.40	0.10	0.40-1.0	4.0-4.9	0.05-0.25	0.25	0.15	0.05	0.15

Figure 138: Composition of EN-AW 5083 used in the metal filler for the welding of the Nicolai frame
Source: http://www.atlassteels.com.au

Appendix 7: Quality form for the assembly of each Nicolai frame.



CHECKLIST

RAHMEN DETAILS | **FRAME DETAILS**

Modell | **model**	G-18
Modelljahr | **model year**	2017
Rahmennummer (Hauptrahmen / Schwinge / Druckstreben) **frame number (main frame / swingarm / seat stays)**	45866-8685-9215-9186
RADO Offset | **dropout offset**	-1

Endmontage | **final assembly**	Datum 30.06.16	Unterschrift EK

TECHNISCHE ABNAHME | **TECHNICAL INSPECTION**

1	Techn. Einregelung des Rahmens | **frame alignment**		
2	Gewinde, Pass- und Planflächen kontrolliert | **thread and fitting surface check**		
3	Montage und Einstellung - Endgültige Überprüfung | **assembly and tuning - final inspection**		

OPTISCHE ENDABNAHME | **FINAL VISUAL INSPECTION**

1	Endkontrolle Bestellung = montierter Rahmen | **final inspection customer order = assembled frame**	SS	[illegible]
2	Prüfen der Oberflächen und der Beschichtung | **surface and coating inspection**	SS	[illegible]
3	Überprüfung aller Zusatzbauteile (z.B. Zugführung etc.) | **check of all additional components (e.g. cable guides etc.)**	SS	[illegible]

HINWEISE | **ATTENTION**

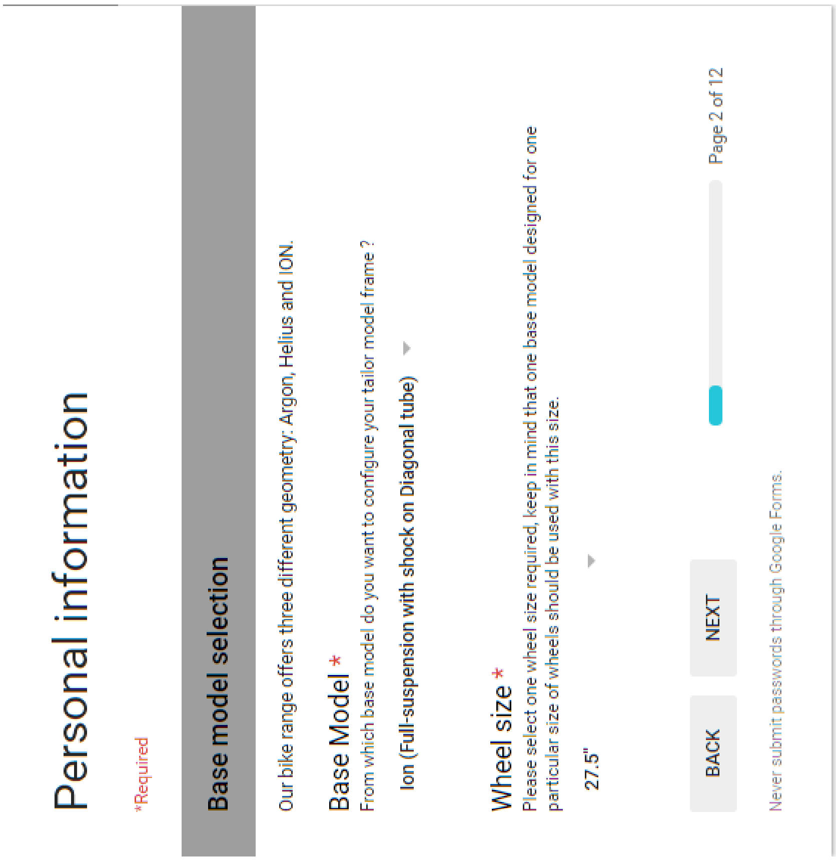
1. Dein neuer NICOLAI Rahmen ist ein Sportgerät und darf nicht ohne entsprechende Sicherheitsausstattung gemäß der StVZO auf öffentlichen Verkehrswegen genutzt werden. Bitte beachte die Richtlinien gemäß den Landesverordnungen.
Your new NICOLAI frame is a piece of sports equipment and it is not equipped with the required safety components for the usage on public roads. Please refer to the guidelines of your country.

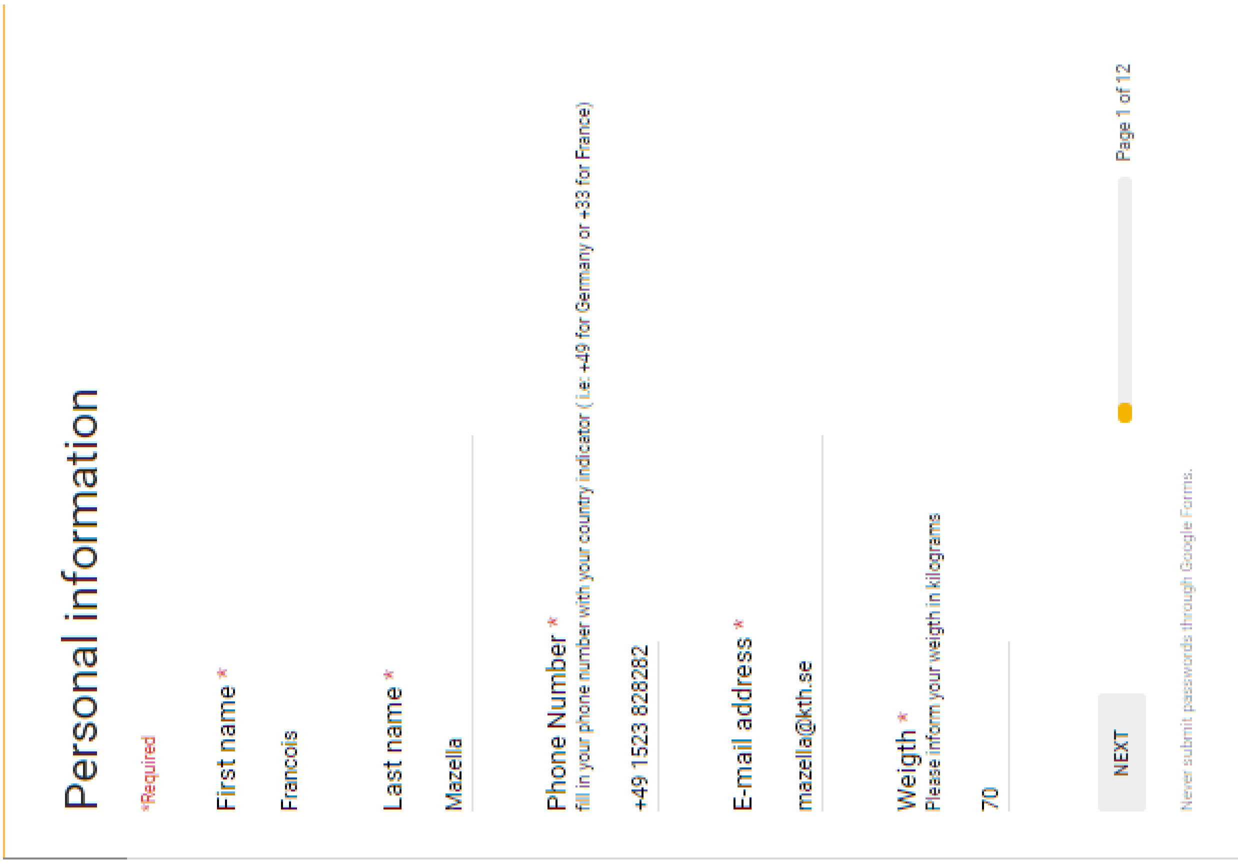
2. Bei der Montage deines Bikes beachte unbedingt auch die Anleitungen der Komponentenhersteller. Solltest du dir bei spezifischen Montageschritten nicht sicher sein, ist die NICOLAI GmbH oder dein lokaler Bikeshop ein sehr guter Ansprechpartner.
Please read the instructions that come with your additional bike components carefully. If you are uncertain about any steps in your assembly process please refer to NICOLAI directly or to your local bikeshop for support.

w³.nicolai.net

Figure 139: Quality form signed by assembling technicians before shipping

Appendix 8: Internet customer form





Rear suspension travel

In this section, you will get information about our suspension travel options and choose accordingly.

Rear supension travel guide

Geometry	Wheel size	Suspension travel (mm)
Helius	27,5"	140
	29"	120
Ion	27,5"	160
		155
	29"	145

Rear suspension travel *

Please select the rear suspension travel in mm according to the geometry and wheel size requested, you can refer to the table above.

- ○ 120 mm
- ○ 140 mm
- ○ 145 mm
- ◉ 155 mm
- ○ 160 mm

BACK NEXT Page 3 of 12

Never submit passwords through Google Forms.

Geometrical information

Pinion Gear box *

If you have requested an Argon geometry, you can select the Pinion Gear box option.

- ○ Pinion Gearbox (ONLY FOR ARGON GEOMETRY)
- ◉ Classical drivetrain

Front tire outside diameter

Please enter the real outside diameter of your front tire in mm. It will allow us to define precisely the BB height of your geometry. If you do not know it yet, you can skip this question.

Your answer

Rear tire outside diameter

Please enter the real outside diameter of your rear tire in mm. It will allow us to define precisely the BB height of your geometry. If you do not know it yet, you can skip this question.

Your answer

Fork length *

Please enter the axle to crown length of your fork in mm

562

Fork Offset *

Please enter the axle to steering axle distance of your fork in mm

46

Headset Type *

Our head tube fits tapered tube 1.5"/1"1/8'. Please choose between ZeroStack Headset (ZS 44 and ZS 56) or External cups for heavy duty (EC 49).

Nicolai Standard: Bottom bearing ZeroStack 56 + Top bearing ZeroStack 44

Seatpost diameter *

Please select the seatpost diameter desired in mm IMPORTANT: For rider over 100KG , 30.9mm is recommended.

31.6

BACK NEXT Page 4 of 12

Rear axle and brake mounts information

Rear axle dimensions and Brake mount standards

	Rear axle dimensions availables and Brake Mount standards associated with it		
	Rear axle dimensions		
	142x12mm		
Ion 15 Ion 16 Ion GPI Ion Geometron Helius TB Helius AC	PM 180		
	Rear axle dimensions		
	157x12mm		
Ion 20	PM180		
	Rear axle dimensions		
	135x10mm	142x12mm adjustable	142x12mm fixed
Argon AM Argon AM-PI Argon TB Argon TB-PI		PM180	PM160
Argon TR Argon TR-PI	IS2000-160		
	Rear axle dimensions		
	135x10mm adjustable	135x10mm fixed	
Argon CX	PM160	IS2000-160	
	Rear axle dimensions		
	170x10mm	177x10mm	
Argon FAT Argon FAT-PI	IS2000-160	PM180	

Select Rear axle dimensions *

Please select the rear axle dimensions desired according to the table above

142x12mm fixed (Argon: AM, AM-PI, TB, TB-PI, Ion: 15, 16, GPI, Geometron, Helius: TB, AC)

BACK NEXT Page 5 of 12

Geometrical information (next)

Bottom Bracket Width *

All our BB are threaded, please select a BB width in mm according to your base model

73 mm (Argon : AM, AM-PI, TB, TB-PI , Ion: 15, 16, GPI, Geometron Helius: TB, AC)

Crank arm length *

please select your crank arm length in mm

170

Head angle *

Please inform which head angle you require in degrees

63

Head tube length *

please select an head tube length in mm, you can refer to the base model techsheet for help.

130

Real seat tube angle *

Please inform in degrees which real seat tube angle you require.

77

Bottom bracket drop *

Please inform in mm which bottom bracket drop you require.

-19

BACK NEXT Page 6 of 12

Chainstay

IMPORTANT:
-For Helius and ION geometries: Nicolai GMBH can offers three different length of swing arms: 435mm ,445mm and 450mm.

-For Argon geometry, you can choose the length you want in the "other" category .

IMPORTANT:

In all geometries ARGON, HELIUS or ION, the chainstay cannot be shorter than the minimum required for the wheel size. Please refer to the table below.

Minimum Chainstay requirement

Geometry	Use	Wheel size	Minimum chainstay length (mm)
Argon	MTB	27,5"	425
		29"	435
	ROAD/CITY	700C	405
Helius/ION	MTB	27,5"	435
		29"	445

Chainstay length *
IMPORTANT: In all geometries ARGON, HELIUS or ION, the chainstay cannot be shorter than the minimum required for the wheel size. Please refer to the table above.

- (selected) 435mm
- 445mm
- 450mm
- Other:

BACK NEXT Page 7 of 12

Geometrical information (next)

seat tube length *
Please inform in mm which seat tube length you require.

470

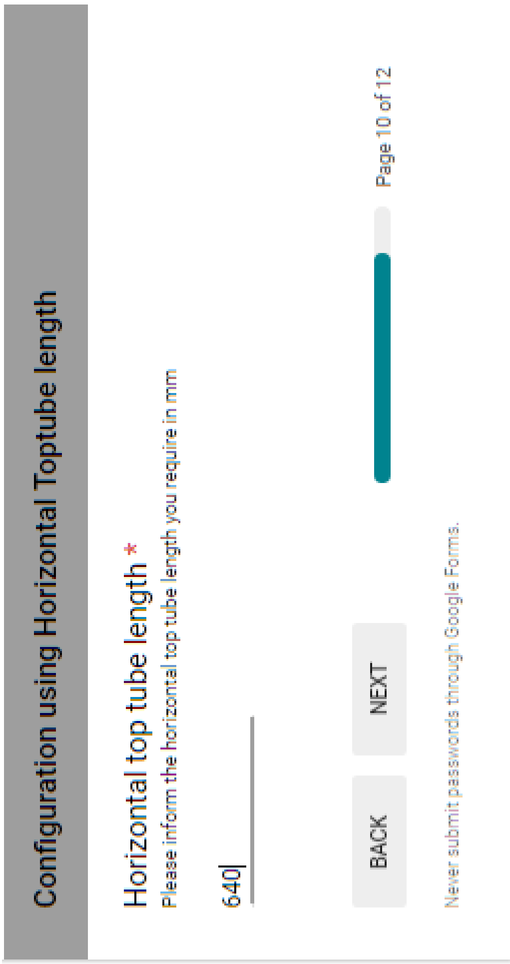
seat-tube offset *
Please inform in mm which seat tube offset you require.

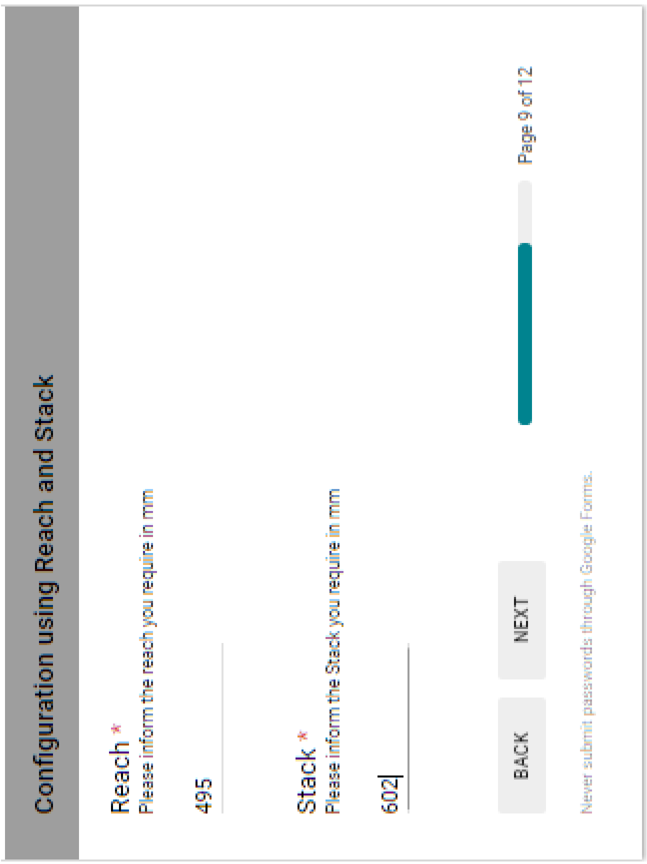
20

How do you want to continue the front triangle configuration? *

- (selected) Using reach + stack
- Using horizontal top tube length

BACK NEXT Page 8 of 12


Configuration using Horizontal Toptube length
Horizontal top tube length *
Please inform the horizontal top tube length you require in mm
640
BACK
NEXT
Page 10 of 12
Never submit passwords through Google Forms.


Configuration using Reach and Stack
Reach *
Please inform the reach you require in mm
495
Stack *
Please inform the Stack you require in mm
602
BACK
NEXT
Page 9 of 12
Never submit passwords through Google Forms.

Additional configuration

Shifting cable routings *

- ◯ rear derailleur only
- ◯ front+rear derailleurs
- ◯ Rolhoff

Rear derailleur and braking cable routings placement *

- ◯ Nicolai Standard: above diagonal tube + above chainstays for rear brake and rear derailleur
- ◯ Under diagonal tube + above chainstays for rear brake and rear derailleur

Front derailleur cable routings placement
If you have selected front+rear derailleurs shifting, please select one routing option.

- ◯ Nicolai Standard: above diagonal tube
- ◯ Under diagonal tube
- ◯ Under top tube

Dropper seatpost cable routing *

- ◯ Nicolai standard: Stealth
- ◯ Stealth+external routing

Bottle cage options available

Geometry	Number of bottle cages available
Argon	2
Helius	1
Ion	0

Bottle cage *
Not all our geometries can offer the same number of bottle cage placements, please refer to the table above.

- ◯ 0
- ◯ 1
- ◯ 2

BACK NEXT Page 11 of 12

Legal information

Informations

Your tailor made bike frame has been fully defined, congratulations! We will analyze your requirements and get in touch with you as soon as our engineering team is availbale!

BACK SUBMIT Page 12 of 12

Appendix 9: Head tube standard

FRAME HEADTUBE ID	BEARING / PRESS OD	INTERFERENCE OR SLIP FIT	DESCRIPTION	SHIS TERM
29.8mm to 29.9mm	30.0mm	Interference fit	Conventional JIS standard for 1-inch steering column, threaded and threadless	EC29
30.0mm to 30.1mm	30.2mm	Interference fit	Conventional "Euro" standard for 1-inch steering column, conventional threaded and threadless	EC30
33.8mm to 33.9mm	34.0mm	Interference fit	Conventional 1-1/8 inch for threadless and threaded	EC34
36.8mm to 36.9mm	37mm	Interference fit	Conventional 1-1/4 inch for threaded and threadless	EC37
38.15mm to 38.14	38mm	Slip fit	Integrated-angular contact 1-inch steering column 36 x 36 degree contact	IS38
41.05 to 41.1mm	41mm	Slip fit	Integrated-angular contact 1-1/8 inch steering column 36 x 45 degree contact "IS" or "Cane Creek® types	IS41
41.3mm	41.4mm	Interference fit	Low Profile 1-1/8" steering column, with headtube outside diameter nominally 47mm Frame has no angular contact.	ZS41
41.55 to 41.6mm	41.5mm	Slip fit	Integrated-angular contact 36 x36 degree contact TH Industries® ED-36 type	Obsolete
41.85 to 41.9mm	41.8mm	Slip fit	Integrated-angluar contact 45 x 45 degree contact Campagnolo® Hiddenset standard	IS42
41.9 to 42mm	42mm	Interference fit	Microtech® Integrated- non-angular contact Frame has no angular contact.	Obsolete
43.9mm	44mm	Interference fit	Low Profile for 1-1/8 inch steering column Cartridge bearing types use slip fit into pressed cup.	ZS44
44.05mm to 44.1mm	44mm	Slip fit	Integrated-angular contact 1-1/8" steering column 36 x 36 degree contact	Obsolete
47.05-47.1	47	Slip fit	Integrated lower only	IS47
49.6mm	49.7mm	Interference fit	Onepointfive® Standard Oversized threadless type	EC49 & ZS49
52.1-52.15	52mm	Slip fit	Integrated lower	IS52
55.90-55.95	56mm	Press fit	Internal and conventional headset	ZS56 & EC56

Figure 140: Summary of headset standard on the bicycle market
Source: Parktool.com

Appendix 10: ISCG standard

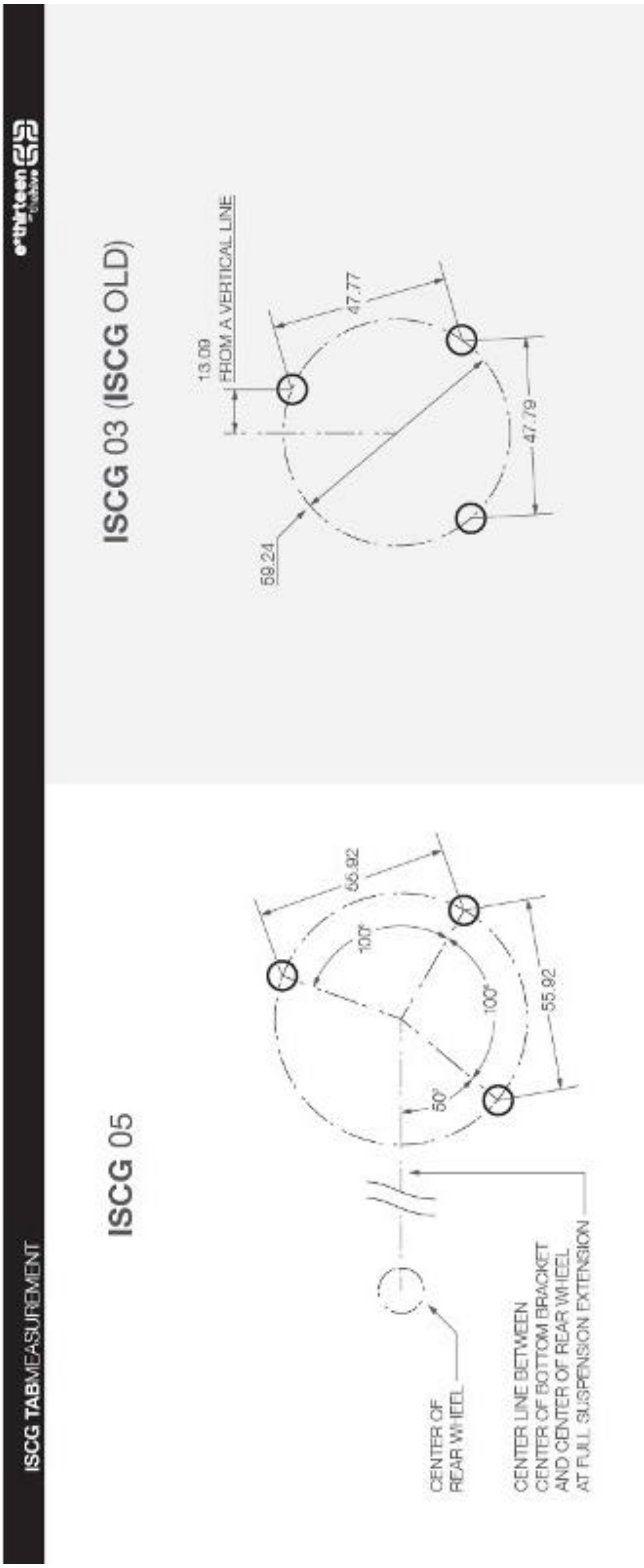


Figure 141: ISCG standards description. Source: http://service.bythehive.com/

Appendix 11: Brake mount standard

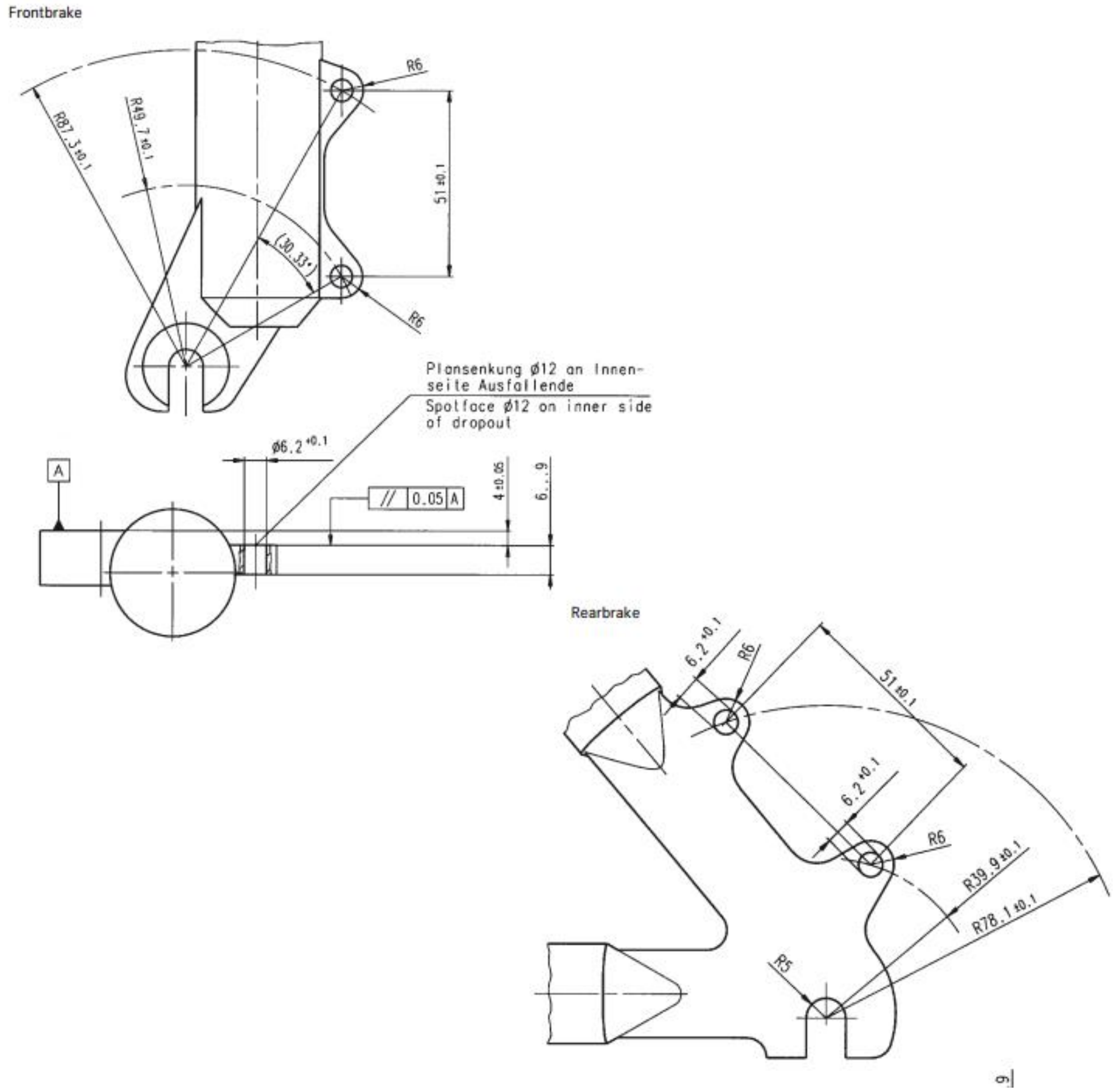


Figure 142: International Standard brake disc mount (I.S)
Source: Magura.com

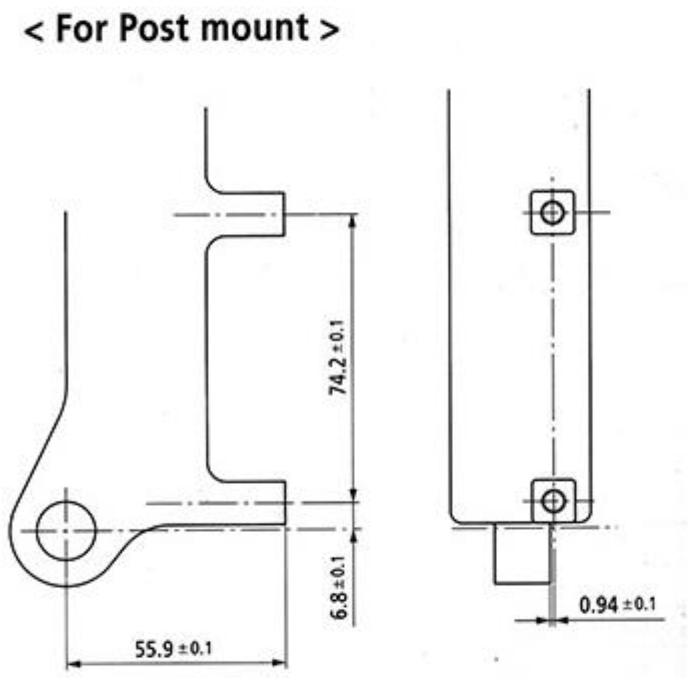
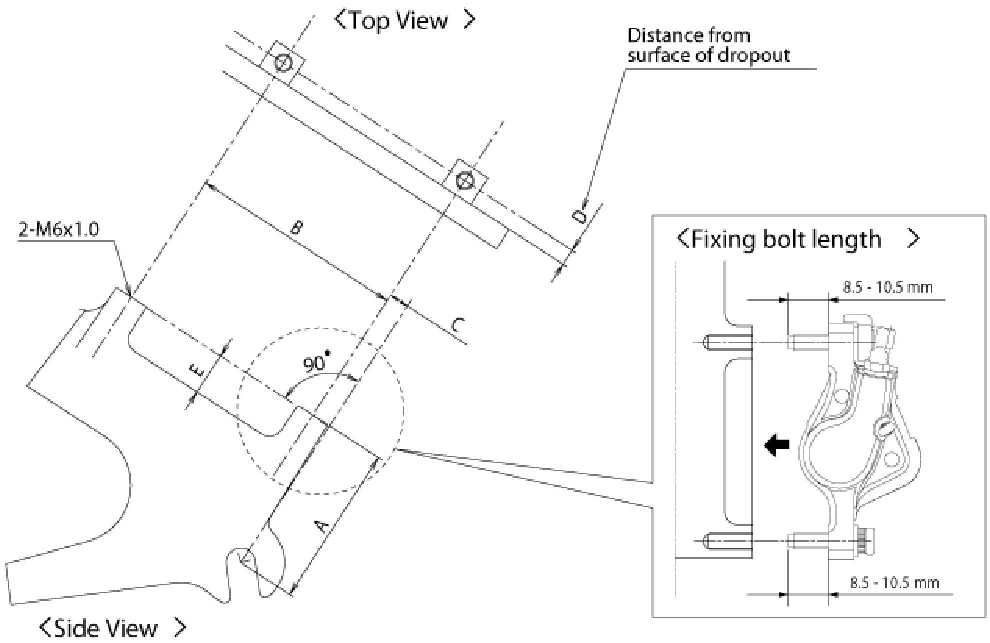


Figure 143:Post mount standard for front wheel
Source: Shimano Builder Info



Dimensions of rear post mount of disc brake caliper

Dimension	Rotor size (mm)				Tolerance
	140	160	180	203	
A	47.5	55.9	64	73.9	±0.1
B	74.2	74.2	74.2	74.2	±0.1
C	1.7	6.8	12.4	18.8	±0.1
D	5.7	5.7	5.7	5.7	±0.1

Figure 144:Post mount standard for rear wheel
Source: Shimano Builder info

Appendix 11: CNC machine description

Machine specifications

item		TC-32BN QT		TC-32BN FT	
		12,000min^{-1} specifications	16,000min^{-1} specifications	12,000min^{-1} specifications	16,000min^{-1} specifications
CNC unit model		CNC-B00		CNC-B00	
Travels	X axis [mm(inch)]	550 (21.7)		550 (21.7)	
	Y axis [mm(inch)]	400 (15.7)		400 (15.7)	
	Z axis [mm(inch)]	415 (16.3)		415 (16.3)	
	Distance between table top spindle nose end[mm(inch)]	645 (25.4)		645 (25.4) (standard), 865 (34.1) (low)	
Table	Work area size [mm(inch)]	600 x 425 (23.6 x 16.7) (one side)		800 x 400 (31.5 x 15.7)	
	Max. loading capacity (uniform load) [kg(lbs)]	200 (441) (one side)		600 (1323)	
	Max. turning diameter [mm(inch)]	1,200 (47.2)		-	
	Table positioning time [sec.]	3.4/180°		-	
	Table chage repeatability [mm(inch)]	0.01 (0.0004) (table center)		-	
Spindle	Spindle speed [min^{-1}]	12 - 12,000	16 - 16,000	12 - 12,000	16 - 16,000
	Speed during tapping [min^{-1}]	MAX.8,000min		MAX.8,000min	
	Tapered hole	7/24 tapered #30 [*9]			
Feed rate	Rapid traverse rate X x Y x Z axes [m(inch)/min]	70 x 70 x 70 (2,756 x 2,756 x 2,756)			
	Cutting traverse rate [mm(inch)/min]	1 - 20,000 (0.04 - 787.4)		1 - 20,000 (0.04 - 787.4)	
ATC unit	Tool shank type	MAS-BT30 [*9]			
	Pull stud type [*8]	MAS-P30T-2 [*9]			
	Tool storage capacity [*1] [pcs.]	26(+1)/40(+1)			
	Max. tool diameter [*2] [mm(inch)]	0 - 30 (0 - 1.2) / D46 (1.8) , 30 - 200 (1.2 - 7.9) / D55 (2.2) (Large tool D125 (4.9))			
	Max. tool length [mm(inch)]	200 (7.9)		200 (7.9)	
	Max. tool weight [*3] [kg(lbs)]	3.5 (7.7)		3.5 (7.7)	
	Tool selection	Double arm method (random shortcut)			
	Tool change	Tool To Tool: 0.9(BT) [*10] Chip To Chip: 2.0(BT) [*10]			
Electric motor	Main spindle motor (10 min / continuous) [*4] [kW]	11/ 6	10/ 7.3	11/ 6	10/ 7.3
	Feed spindle motor [kW]	1.3 (X, Y, Z)		1.3 (X, Y, Z)	
Power source	Power supply	AC 3Φ, 50 / 60Hz ± 1Hz			
	Power capacity [*5] [kVA]	16 (Max. 32)	18 (Max. 37)	16 (Max. 32)	18 (Max. 37)
	Air supply: Working air pressure	0.4MPa - 0.6MPa		0.4MPa - 0.6MPa	
	Air supply: Required flow [*6]	120 L/min (at atmospheric pressure)			
Machining dimensions	Machine height [mm(inch)]	2,360 (92.9)		2,360 (92.9)	
	Required floor space (with control unit door open)[mm(inch)]	1,890 x 3,669 (74.4 x 144.4)		1,890 x 3,103 (74.4 x 122.2)	
	Machine weight (including control unit splash guard) [kg(lbs)]	4,600 (10,143)		4,400 (9,702)	
Accuracy [*5]	Positioning accuracy [mm(inch)]	0.005 / 300 (0.0002 / 11.8)		0.005 / 300 (0.0002 / 11.8)	
	Repeatability [mm(inch)]	± 0.003 (± 0.00012)		± 0.003 (± 0.00012)	

Figure 145: Description of CNC machine Brother TC-32BN QT
Source: Brother.com