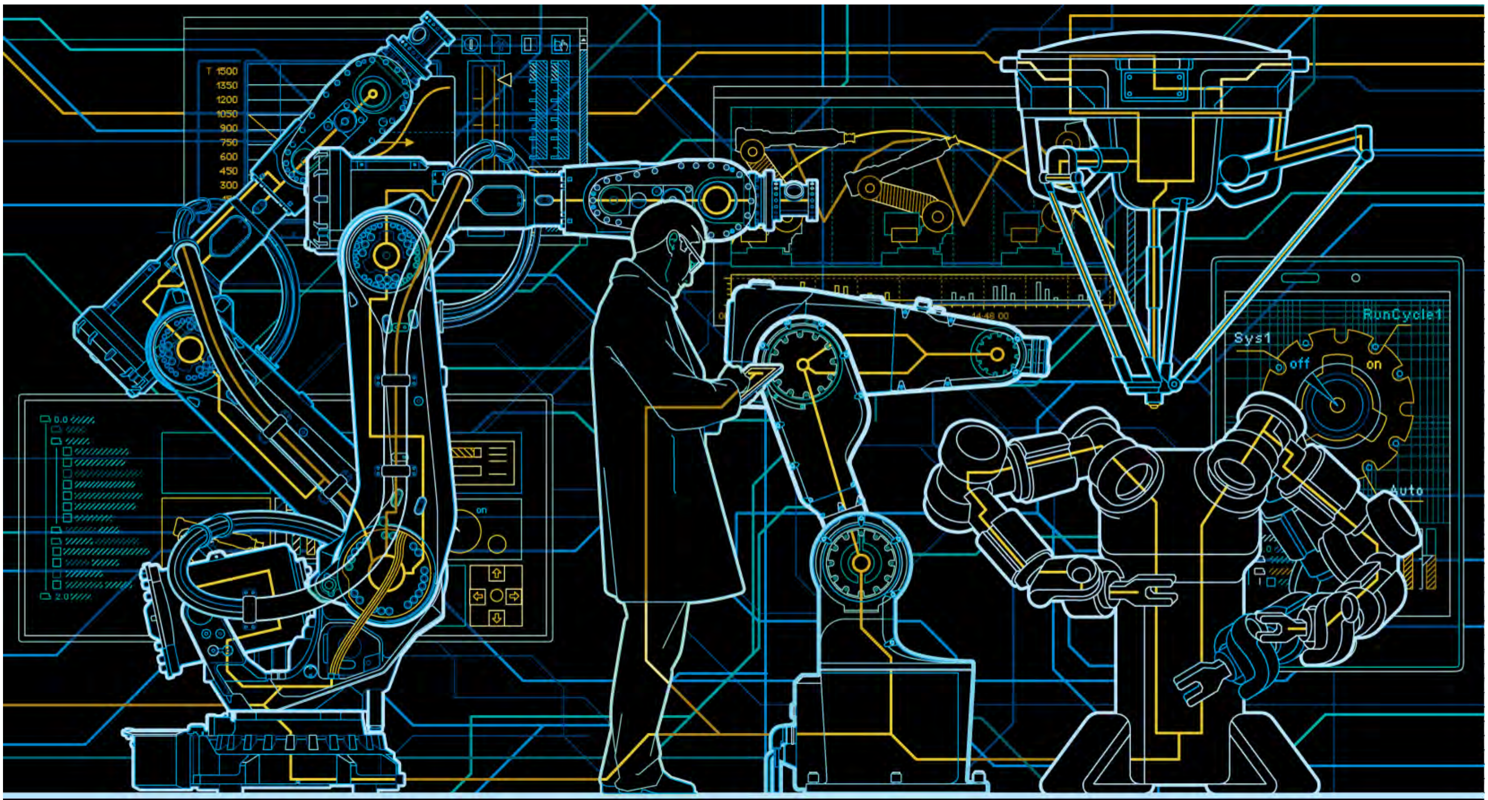

Application manual
Servo gun tuning

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Application manual
Servo gun tuning

RobotWare 6.04

Document ID: 3HAC026820-001
Revision: D

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Table of contents

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Overview of this manual

About this manual

This manual details the necessary procedures for tuning a servo gun on the IRC5 controller. It covers the essentials for tuning the most commonly used types of servo guns.

This includes tuning and verification of a subset of the motion parameters used to configure a servo gun on the IRC5 controller. For a complete documentation on these and other motion parameters, see the *Application manual - Additional axes and stand alone controller*.

Usage

This manual should be used during tuning of a servo gun.

Who should read this manual?

The intended audience are servo gun manufacturers or advanced users, who need to tune a servo gun.

Prerequisites

The reader should be familiar with:

- IRC5 programming and usage
- Additional axes (see *Application manual - Additional axes and stand alone controller*)
- RobotWare Spot Servo (see *Application manual - Spot options*)
- Test Signal Viewer

Organization of chapters

The manual is organized in the following chapters:

Chapter	Contents
1	Short description of servo gun tuning and what is required before starting.
2	Description of how to configure some system parameters that need to be set before tuning begins.
3	Calibration and system parameters to set in order to define the servo gun position.
4	Set up Test Signal Viewer and look at the speed and torque of the servo gun.
5	Tuning to optimize the position control part of the servo gun motion.
6	Tuning to optimize the force control part of the servo gun motion.
7	Tuning to optimize the acceleration of the servo gun.
8	Set up and execute the `Calibrate` routine.

References

Reference	Document ID
Application manual - Additional axes and stand alone controller	*3HAC051016-001*

Continues on next page

Reference	Document ID
Application manual - Spot options	*3HAC050979-001*
Application manual - Mechanical Unit Manager	*3HAC050959-001*
Operating manual - IRC5 with FlexPendant	*3HAC050941-001*
Operating manual - RobotStudio	*3HAC032104-001*
Technical reference manual - System parameters	*3HAC050948-001*
Technical reference manual - RAPID Instructions, Functions and Data types	*3HAC050917-001*
Application manual - Mechanical Unit Manager	*3HAC050959-001*

Note

The document numbers that are listed for software documents are valid for RobotWare 6. Equivalent documents are available for RobotWare 5.

Revisions

Revision	Description
-	First edition.
A	Minor corrections
B	Released with RobotWare 6.01. • Corrections and updates throughout the manual.
C	Released with RobotWare 6.02. • Updated the path to the template files, see *Template files on page 18*. • Added system parameter *Force Detection Min Time*, see *Torque ramp on page 39*.
D	Released with RobotWare 6.04. • Added information about the parameter *Force Control Motor Torque*, see *Replace in type SG Process on page 21*.

Product documentation, IRC5

Categories for user documentation from ABB Robotics

The user documentation from ABB Robotics is divided into a number of categories. This listing is based on the type of information in the documents, regardless of whether the products are standard or optional.

All documents listed can be ordered from ABB on a DVD. The documents listed are valid for IRC5 robot systems.

Product manuals

Manipulators, controllers, DressPack/SpotPack, and most other hardware is delivered with a **Product manual** that generally contains:

- Safety information.
- Installation and commissioning (descriptions of mechanical installation or electrical connections).
- Maintenance (descriptions of all required preventive maintenance procedures including intervals and expected life time of parts).
- Repair (descriptions of all recommended repair procedures including spare parts).
- Calibration.
- Decommissioning.
- Reference information (safety standards, unit conversions, screw joints, lists of tools).
- Spare parts list with exploded views (or references to separate spare parts lists).
- Circuit diagrams (or references to circuit diagrams).

Technical reference manuals

The technical reference manuals describe reference information for robotics products.

- *Technical reference manual - Lubrication in gearboxes*: Description of types and volumes of lubrication for the manipulator gearboxes.
- *Technical reference manual - RAPID overview*: An overview of the RAPID programming language.
- *Technical reference manual - RAPID Instructions, Functions and Data types*: Description and syntax for all RAPID instructions, functions, and data types.
- *Technical reference manual - RAPID kernel*: A formal description of the RAPID programming language.
- *Technical reference manual - System parameters*: Description of system parameters and configuration workflows.

Continues on next page

Application manuals

Specific applications (for example software or hardware options) are described in **Application manuals**. An application manual can describe one or several applications.

An application manual generally contains information about:

- The purpose of the application (what it does and when it is useful).
- What is included (for example cables, I/O boards, RAPID instructions, system parameters, DVD with PC software).
- How to install included or required hardware.
- How to use the application.
- Examples of how to use the application.

Operating manuals

The operating manuals describe hands-on handling of the products. The manuals are aimed at those having first-hand operational contact with the product, that is production cell operators, programmers, and trouble shooters.

The group of manuals includes (among others):

- *Operating manual - Emergency safety information*
- *Operating manual - General safety information*
- *Operating manual - Getting started, IRC5 and RobotStudio*
- *Operating manual - IRC5 Integrator's guide*
- *Operating manual - IRC5 with FlexPendant*
- *Operating manual - RobotStudio*
- *Operating manual - Trouble shooting IRC5*

Safety

Safety of personnel

A robot is heavy and extremely powerful regardless of its speed. A pause or long stop in movement can be followed by a fast hazardous movement. Even if a pattern of movement is predicted, a change in operation can be triggered by an external signal resulting in an unexpected movement.

Therefore, it is important that all safety regulations are followed when entering safeguarded space.

Safety regulations

Before beginning work with the robot, make sure you are familiar with the safety regulations described in the manual *Operating manual - General safety information*.

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1 Introduction

1.1 About servo gun tuning

Basic approach

This is the general approach for setting up and tuning a servo gun.

1. Load a template configuration file. See *Template files on page 18*.
2. Define motor parameters for the servo gun. See *Parameter initialization on page 20* and *Motor commutation on page 22*.
3. Perform a fine calibration. See *Fine calibration on page 23*.
4. Set parameters for transmission and working range. See *Kinematics on page 24* and *Working range on page 26*.
5. Set up Test Signal Viewer and verify speed and torque. See *Basic verification on page 27*.
6. Tune parameters for position control. See *Position control on page 31*.
7. Tune parameters for force control. See *Force control on page 33*.
8. Tune parameters for gun acceleration. See *Accelerations on page 51*.
9. Set up and run the `Calibration` routine. See *Calibration procedure on page 55*.

Tip

In order to reduce the time it takes to tune a set of servo guns, it is recommended to classify all guns into gun families and then reuse the parameters set for one gun for all other guns within the same family. See *About servo gun tuning on page 13*.

Gun families

Within the same family, guns share mechanical characteristics such as motor, transmission ratio, friction (to some extent), stiffness, inertia, max allowed force, arm length and max opening distance.

The force may vary somewhat between guns of the same family. The reason is that the friction level, which has some influence on force, often differs a lot within the family. Therefore a `Force Calibration` and an update of the parameter `Collision Delta Position` should always be done for each individual gun.

Gun design

The design of the gun also affects the tuning procedure. Flexible copper gun arms driven by linear actuators are the easiest guns to tune. Aluminum arms are rigid and present a challenge.

The recommendations and start values in this manual are mainly intended for guns with copper arms.

Continues on next page

Tuning scenarios

This section is a suggestion on how to use this manual in order to speed up the tuning process.

New guns

Scenario	Proposed chapters
No similar gun tuned before	Chapter 2 - 8
Identical to an already tuned gun	*Force calibration on page 50* *Identify Collision Delta Position on page 55*
Hardware identical to an already tuned gun, but different weld force	Chapter 6 starting at *Find the maximum torque (protect the gun) on page 36* Chapter 7 - 8

Guns in production

Scenario	Proposed chapters
Servo motor replaced with a different motor	Chapter 2 - 8
Servo motor replaced with an identical motor	*Force calibration on page 50* *Identify Collision Delta Position on page 55*
Gun arm replaced with a different arm	Chapter 3 - 8, and a TCP calibration
Gun arm replaced with an identical arm	None, but a TCP calibration is recommended
Replacement of any bushing that affects gun friction	Chapter 6 starting at *Friction on page 34* Chapter 7 - 8
Calibration instructions do not work, i.e. false hit	Chapter 6 starting at *Friction on page 34* Chapter 7 - 8

CAUTION

Gun tuning is complicated, even in the best of conditions. By starting midway into the tuning procedure, or changing the order of the steps, it is very easy to make a mistake that makes the gun behave in a way that is not covered in this manual.The suggestions above should only be attempted by persons experienced in gun tuning.

1.2 Requirements

Requirements on motor and resolver

The motor and resolver should comply with the requirements given in *Application manual - Additional axes and stand alone controller*.

Spot Servo option required

Use a system with the RobotWare Spot Servo option installed.

Test Signal Viewer

The Test Signal Viewer program is a part of RobotWare and can be found in the installation.

System parameters

When following the procedures of this manual, you will need to set values to several system parameters. Detailed description of these parameters are found in *Technical reference manual - System parameters*.

How to set system parameters with RobotStudio is described in *Operating manual - RobotStudio*.

How to set system parameters with the FlexPendant is described in *Operating manual - IRC5 with FlexPendant*.

How to set system parameters with Mechanical Unit Manager is described in *Application manual - Mechanical Unit Manager*.

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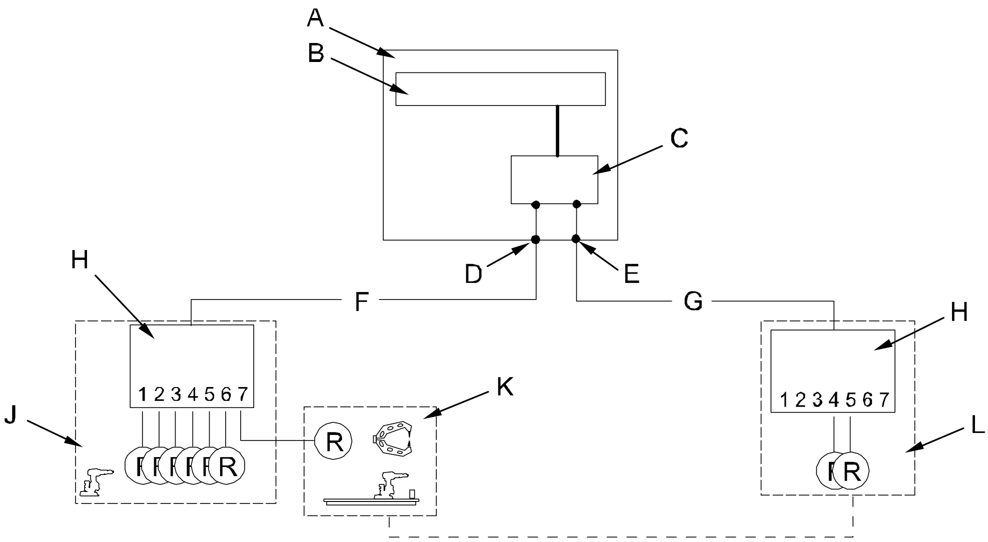
2 Configuration

2.1 Hardware configuration

Example description

The following is an example of a setup with two serial measurement boards on two measurement links, for example servo gun or track motion. If both servo gun and track motion are to be used, the track motion is connected to serial measurement link 2 and resolver node 5.

Parts



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Part number	Description
A	IRC5 controller
B	Main computer
C	Axis computer
D	Serial Measurement Link 1 connector XS.2
E	Serial Measurement Link 2 connector XS.41
F	Serial Measurement Link 1
G	Serial Measurement Link 2
H	Serial Measurement Board
J	Six axes robot system
K	Servo gun
L	Axes 8-9
R	Resolvers

2.2 Template files

About template files

When the system is delivered, the *Motion* configuration topic does not include any parameters for the servo gun. The user has to load them separately.

When tuning a servo gun, a template file with start values appropriate for the tuning procedure should be loaded. It is important to know which hardware is used on the IRC5 controller in order to load the correct template file. For more information, see *Application manual - Additional axes and stand alone controller*.

The template files for servo guns are located in the *Utility* folder in RobotWare.

The template files for servo guns are located in the following directory in the RobotWare installation:
...\RobotPackages\RobotWare_RPK_<version>\utility\AdditionalAxis\ServoGun.

Note

Navigate to the RobotWare installation folder from the RobotStudio **Add-Ins** tab, by right-clicking on the installed RobotWare version in the **Add-Ins** browser and selecting **Open Package Folder.**

The template files have the following identification: M*x*L*y*B*z*S_DM*d*.CFG

- *x* is the motor (logical axis)
- *y* is the measurement link
- *z* is the board position
- *d* is the drive module

Load the servo gun template file

The template file can be loaded either by using the FlexPendant or using RobotStudio. Read the procedure below for the tool of your choice.

Tip

To be able to get back to the starting point in case of any problems, it is highly recommended to take a backup of the *Motion* parameters.

CAUTION

If the system already has servo gun parameters, it is recommended to load *Motion* parameters without the servo gun configuration.

Load template file using the FlexPendant

1. On the ABB menu, tap **Control Panel** and then **Configuration**.
2. Tap **File** and then **Load Parameters**.
3. Select **Load parameters and replace duplicates** and tap **Load**.
4. Browse to the template file you wish to use. Select the file and tap **OK**.
5. Restart the system in order for the changes to take effect.

Continues on next page

For more details, see *Operating manual - IRC5 with FlexPendant*.

Load template file using RobotStudio

1. In the **Robot View Explorer** right-click the configuration node and then select **Load Parameters**.
2. Select **Load parameters and replace duplicates**.
3. Click **Open** and browse to the configuration file to load. Then click **Open** again.
4. Confirm by clicking **OK**.
5. Restart the system in order for the changes to take effect.

For more details, see *Operating manual - RobotStudio*.

2.3 Parameter initialization

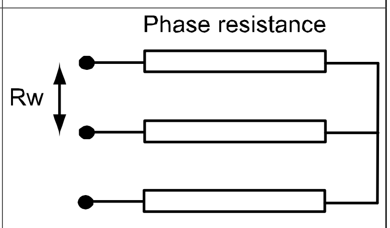
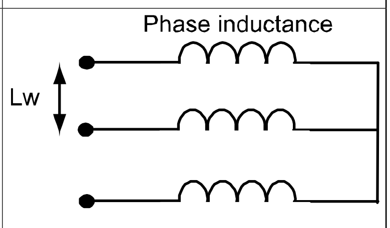
Note

Make sure that all parameters are entered in SI units. Some parameters are not always given in SI units from the motor/gun manufacturer and need to be converted.

Replace in type Motor Type

All motor type parameters shall be supplied by the motor manufacturer.

Define the following parameters in the type *Motor Type* in the topic *Motion*.

Parameter	Description	Illustration
Pole pairs	Number of pole pairs of the motor.	
Ke phase to phase	Nominal voltage constant (Vs/rad). If the motor manufacturer gives the torque constant Kt, calculate Ke from: $Ke = \frac{Kt}{\sqrt{3}}$ xx0600002822	
Max current	Maximum current for the motor (A).	
Phase resistance	Stator resistance between each winding (Ω). If the motor specification is with values between the phases Rw, use the following calculation: $Phase\ resistance = \frac{Rw}{2}$ xx0600002823	 xx0600002827
Phase inductance	Stator inductance between each winding (H). If the motor value is given with values between the phases Lw, use the following calculation calculation: $Phase\ inductance = \frac{Lw}{2}$ xx0600002825	 xx0600002828
Stall torque	The stall torque (Nm).	

Continues on next page

Replace in type Stress Duty Cycle

Define the following parameters of the type *Stress Duty Cycle* in the topic *Motion*.

Parameter	Description
Speed Absolute Max	The maximum speed of the servo motor (rad/s). If the maximum motor speed is given in rpm, convert it to rad/s: $speed_{rad/s} = \frac{2\Pi}{60} \times speed_{rpm}$ xx0600002829 Example: 3300 rpm = 345 rad/s **Note** The maximum possible speed of the motor is limited by the IRC5 drive system. The available motor torque (defined by *Torque Absolute Max*) starts to drop to zero at a certain speed level, the rated speed. The rated speed can be given by the motor supplier for the voltage level of the drive system. However, the resulting rated speed with the IRC5 drive system might deviate somewhat from this value.It depends on the characteristics and the performance of the IRC5 drive system with this particular motor. Set *Speed Absolute Max* <= the rated speed in order to avoid the limitation.
Torque Absolute Max	The maximum motor torque that the drive system will provide (Nm). Correctly defined, it will protect the motor and the gun from damage. The highest possible value can be calculated from: $\textit{Torque Absolute Max} = Ke \times \sqrt{3} \times \textit{Max current}$ xx0600002830 This calculated torque is most likely higher than the gun itself can handle. To have some safety margin, set *Torque Absolute Max* to 10 if the calculated value is higher than this.

Replace in type SG Process

Define the following parameters in the type *SG Process* in the topic *Motion*.

Parameter	Description
Force Control Motor Torque	Max motor torque that the system will provide during force control (Nm). If a higher force than the force corresponding to this value is requested by the application program, the achieved torque will automatically be limited to this value. The torque value set in *SG Process* should be the value set by the gun manufacture specification, and is the torque the gun can handle in contact. If this is not clear, please contact the gun manufacturer to get the accurate setting. The torque value set in *Stress Duty Cycle* can be a higher value, since in most cases there will be less mechanical stress on the gun while the gun is moving without contact. A typical value of *Torque Absolute Max* in *Stress Duty Cycle* is *1.3*Force Control Motor Torque*, but the value should never be higher than *Ke*sqrt(3)*Max current*.

2.4 Motor commutation

Note

It is very important that the commutation offset is absolutely correct. Otherwise, the tuning has to be redone.

A symptom of bad commutation offset is that the motor requires very high (too high) torque to move. If the commutation is very bad, motion supervision errors will occur when trying to jog the motor.

Commutation offset given by the motor manufacturer

If the commutation offset is specified by the motor supplier:

1. Enter the value in the parameter *Commutator Offset* in the type *Motor Calibration*.
2. Restart the controller.

Commutation offset unknown

If the commutation value is unknown, it is necessary to commutate the motor. Carefully follow the instructions in *Application manual - Additional axes and stand alone controller*.

3 Position

3.1 Fine calibration

Jog carefully

Now the system has the basic set of parameters needed to carefully jog the servo gun.

CAUTION

Be careful when operating the gun, since the system limitation of force, motor torque and working range is incomplete at this stage.

Perform fine calibration

1. Jog the gun carefully to tip contact without force.
2. Select from menu **ABB - Calibration**.
3. Select the servo gun.
4. Select the tab **Calib. Parameters** and tap on **Fine Calibration**.
5. Select the axis for the servo gun and tap **Calibrate**.

Tip

If it is impossible to jog the gun, and instead you get a joint collision error, verify that:

- the gun is not physically stuck
- the motor phases are connected correctly
- the resolver is connected correctly
- that commutation is OK

3.2 Kinematics

Transmission gear ratio

The kinematics is defined by the parameter *Transmission gear ratio* in type *Transmission*.

The gear ratio is the number of motor revolutions required to move the gun tip a certain distance. The unit is rad/m.

Sign of gear ratio

Jog the servo gun carefully in the direction towards higher position values as indicated by the jogging menu.

Check that...	Action otherwise
the motor shaft rotates clockwise, seen from the shaft side.	If the motor shaft rotate counter clockwise, check the motor phase connections.
the gun opens.	If the gun closes, change the sign of the gear ratio and restart the controller.

Enter a known gear ratio

If the gear ratio is known:

1. Enter the value in *Transmission Gear Ratio*.
2. Restart the controller.

Trim the gear ratio

Use the following procedure if the gear ratio is unknown.

1. Open the gun about 5 mm and read the jog position value on the FlexPendant. Call this value *A_jog_screen*.
2. Measure the gap between the tips. It is recommended to use a measurement tool to get an accurate value. Call this value *A_measured*.
3. Open the gun about 15 mm and read the jog position value on the FlexPendant. Call this value *B_jog_screen*.

   The delta distance B - A should not be too high if a gun of the X-type is used. This is because the gear ratio is more non-linear (position dependent) with this type of gun.
4. Measure the gap between the tips. It is recommended to use a measurement tool to get an accurate value. Call this value *B_measured*.
5. Read the value in *Transmission Gear Ratio* in the type *Transmission*. Call this value *old_transm_joint*.
6. Calculate the new transmission gear ratio value with the following equation:

$$\frac{\text{B\_jog\_screen} - \text{A\_jog\_screen}}{\text{B\_measured} - \text{A\_measured}} \times \text{old\_transm\_joint}$$

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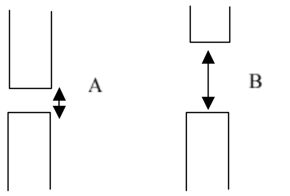

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7. Enter this value in *Transmission Gear Ratio*.
8. Restart the controller and measure that the position information given in the jog screen matches the physical tip position.

3.3 Working range

Set joint boundaries

1. Set the parameter *Upper Joint Bound* in the type *Arm* with the maximum opening given by the gun manufacturer. This parameter defines the maximum opening stroke (m).

   In case you do not have this value, try to find out this value by jogging the gun with a careful jog movement.
2. Set the parameter *Lower Joint Bound* in the type *Arm* to -0.005. This parameter defines the minimum opening stroke (m). A negative value is needed in order to keep the gun inside the working range if a stop occurs during force control.
3. Restart the controller.

Note

If the servo gun is very soft, that is, deflection at maximum force larger than 5 mm, the parameter *Lower Joint Bound* may need to be adjusted (for example -0.010).

4 Basic verification

Prerequisites

Find out if there are any basic problems (i.e. bad parameters or ripple). These problems must be fixed before the tuning of force and position control is started.

For complete speed tuning, see *Application manual - Additional axes and stand alone controller*.

Add servo gun to gun array

Make sure that the spot application is set up correctly. In order to initialize the gun data, you may need to run the service routine `ManAddGunName`. This will find your servo guns in the system, and add their names to the gun array used by the service routines.

From the program editor on the FlexPendant, select **Debug**, tap **Call Routine** and then **ManAddGunName.**

Example

If the servo gun named "RGUN_1" is added to the array position 1, the numerical parameter `GunNo` for the instruction `IndGunMove` should be 1 (or `gun1` which is a constant with value 1).

Define test signals with Test Signal Viewer

The following test signals should be defined for the servo gun:

Signal	Recommended scale
6 speed	0.1
9 torque_ref	1
18 position	1 (or set to 1000/Gear Ratio, to get the value in mm on the arm side)
55 positive torque_limit	1
56 negative torque_limit	1
5 force mode	5
4 speed_ref	0.1

These (and only these) signals are needed from now on during the rest of the tuning procedure.

Note

Do not use any filter. Do not change the sample time.

Run a test program

Create a program with two `IndGunMove` instructions (do not use `MoveJ`, `MoveL` or `MoveAbsJ` instructions, as their accelerations are slightly lower than the asynchronous `IndGunMove`). The gun shall be moved back and forth without the tips getting in contact. The movement shall last long enough to reach the maximum speed.

Continues on next page

Run the program in auto mode (to get full speed) and log the Test Signal Viewer signals.

Note

`IndGunMove` activates independent gun mode. This means that synchronous movements (`MoveJ`, `MoveL`, `MoveAbsJ`) will only move the robot but not the gun. To leave independent mode, execute the instruction `IndGunMoveReset`.

Verify speed and torque

Check the recorded Test Signal Viewer signals.

Maximum speed not reached

If the gun cannot reach the maximum speed although acceleration time is enough check the positive and negative torque limit in Test Signal Viewer. If the torque limits are significantly reduced (>25%) at high speed, this indicates that the maximum speed of the motor with respect to the drive system performance is reached. Reduce the parameter *Speed Absolute Max* in the type *Stress Duty Cycle*.

Torque limit reached

If the torque reaches the torque limits:

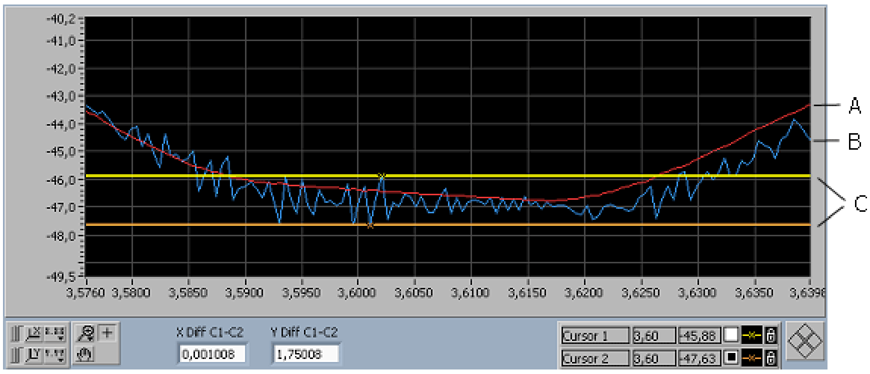
1. Make sure the motor commutation is correctly defined.
2. Reduce accelerations. Decrease *Nominal Acceleration* and *Nominal Deceleration* in type *Acceleration Data*.
3. Increase *Torque Absolute Max* in type *Stress Duty Cycle* carefully.

WARNING

This will allow a higher force on the gun!

Check the speed ripple

Calculate the speed ripple as the peak to peak value of the speed signal when running at constant maximum speed (see example below).



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A	speed_ref
B	speed

Continues on next page

C	Markers placed on the peak values. The distance between these are shown in **Y Diff**. Since the scaling of the speed curve is 0.1, the Y Diff value 1.75 shows that the speed ripple in this case is 17.5 rad/s.

If the speed ripple is less than 30 rad/s, the result is OK. If the speed ripple is very high, the motor torque will become unstable as well.

If the speed ripple is very high reduce *Kv* in type *Lag Control Master* to 50% of the original value. If this does not significantly decrease the ripple, the reason for the high ripple level might be:

- improper shielding and/or grounding of the resolver connector/cable.
- external magnetic fields from process equipment or process cables disturbing the analogue resolver signals between the resolver and the serial measurement board.
- that the natural ripple from the motor is too high. There is always a source of natural ripple from the motor and the resolver. The level is different with different motor types.
- magnetic fields from the motor brake winding disturbing the analogue resolver signals.

A high ripple level may cause motion supervision to frequently stop the system. It has a negative impact on the lifetime of motor and gun. In addition, the tuning will be bad.

Leave independent mode

Execute the instruction `IndGunMoveReset` to leave independent mode.

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5 Position control

5.1 Tuning of movements

About optimizing the movements

This part deals with optimizing the movements of the servo gun. Optimal movements decreases cycle times, improves the path accuracy and minimizes overshoots at stop points. Optimal movements also increases the force accuracy by giving a smooth switch between position control and force control

What tuning is required?

For most servo guns, the default tune values will work fine. Only the Kv tuning needs to be done/checked. However, if the servo gun has some kind of extreme characteristic, for example very high inertia, a thorough tuning of the position control may improve the performance significantly.

Kv defines the gain in the speed control loop.

Complete tuning procedure

A complete description of tuning the position control is found in *Application manual - Additional axes and stand alone controller*. This procedure includes tuning of *Kv*, *Kp*, *Ti*, *Acceleration*, *Deceleration* and other parameters.

This procedure can also be used for servo guns with the following restriction:

- FFW mode = 1 (Spd). Feed forward mode should normally always be Spd for servo guns, although the other modes are possible.

Note

At this point there is no need to optimize the accelerations, defined by *Nominal Acceleration* and *Nominal Deceleration*, since the maximum allowed motor torque not yet is known. This tuning is made after the force control tuning is ready.

5.2 Tuning Kv

Tuning procedure

1. Reuse the test program from the section *Basic verification on page 27*. The gun shall be running long fast movements back and forth in automatic mode.

   Use the `TuneServo` instruction to modify the *Kv* value.
2. Watch the `torque_ref` curve in Test Signal Viewer.
3. Increase the *Kv* value carefully by 5% in each motion loop, until the torque curve starts to become unstable.

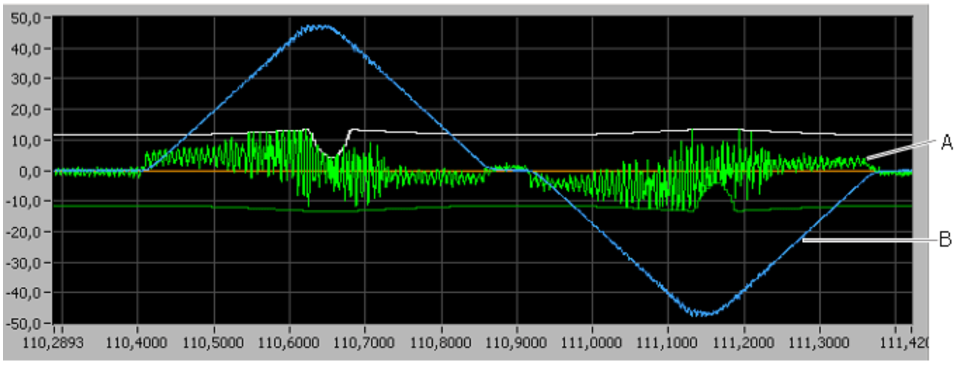
   Indications that the torque curve is unstable:

   - the curve oscillates with significantly higher frequency and amplitude
   - the axis vibrates/oscillates and a clear vibration noise/sound may be heard
   - a motion speed supervision error may occur.
4. Define *Kv* as 40% of the highest stable *Kv* value from the tuning procedure.

   Update *Kv, Gain Speed Loop* in *Lag Control Master 0* and *Uncalibrated Control Master 0* with this value.

Illustration

This is an illustration of a `torque_ref` curve when the *Kv* is too high. Note that the `torque_ref` oscillates significantly when the speed i high.



xx0600003003

A	torque_ref
B	speed

Example

The value of *Kv*, *Gain Speed Loop* in *Lag Control Master 0* and *Uncalibrated Control Master 0* is 0.6.

The `torque_ref` curve becomes unstable after increasing *Kv*, using `TuneServo` instruction, to 285%.

The curve is stable with 280%.

The new *Kv* value is 40% of 280% of 0.6 = 0.4*2.8*0.6 = 0.672

6 Force control

6.1 About this chapter

Optimize force control

The focus in this chapter is mainly the force control part of the gun motion. The aim is to get optimal force accuracy, force repeatability and force build-up time.

6.2 Friction

About friction

The minimum possible force is limited by the friction of the gun. A lower torque than the friction at zero speed will not create a force on the tips. Normally, most of the servo gun friction originates from the gear box.

The friction is higher with a cold motor than with a warm. The friction normally decreases after some time of operation/usage. High friction decreases the performance of the servo gun (cycle time, accuracy in path and force).

Identify the friction

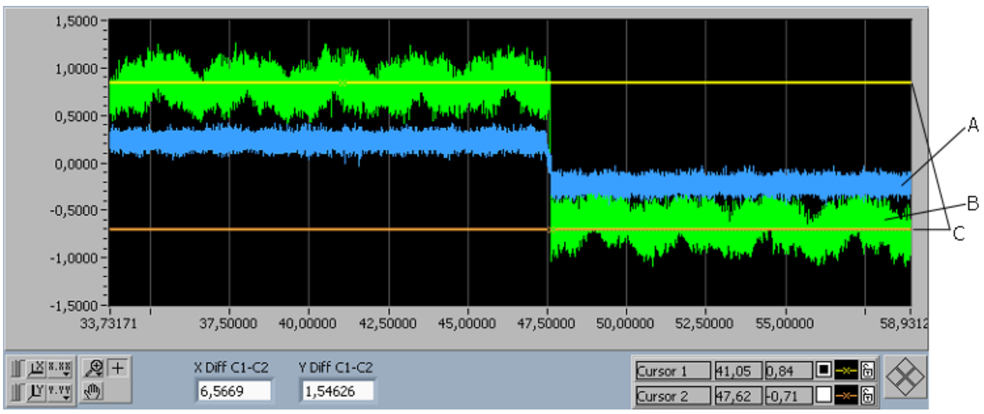
Make a program with two `MoveJ`, moving the tips forward and backward a long distance with slow speed. Use 6 mm/s for the linear axis in the speed data. The tips shall never be in contact during the movements.

Make sure the motor is cold when the program is started.

If the gun does not move when starting the program, make sure that the gun is not in independent mode. If so, execute `IndGunMoveReset` to leave independent mode.

Measure the following torque levels with Test Signal Viewer:

- The average torque level required to move the gun forward at constant speed. Call this value *torque_forward*.
- The average torque level required to move the gun backward at constant speed. Call this value *torque_backward*.



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A	speed
B	torque_ref
C	Markers placed on average torque forward and average torque backward. The values corresponding to these markers are shown at **Cursor 1** and **Cursor 2** (in this case 0.84 and -0.71).

Continues on next page

The friction torque of the servo gun is calculated from:

$$\text{Static\_friction} = \text{abs}\left(\frac{\text{start\_torque\_forward - start\_torque\_backward}}{2}\right)$$

$$\text{Low\_speed\_friction} = \text{abs}\left(\frac{\text{torque\_forward - torque\_backward}}{2}\right)$$

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This way of calculating the friction levels will remove the influence of gravity torque (which often, but not always, is low for a servo gun) since the sign of the gravity torque is equal for the forward and backward movement.

Save these values for later use. They will later be used to calculate the parameter *Collision Alarm Torque* and *Calibration force low*, see *Define the calibration routine parameters on page 55*.

6.3 Find the maximum torque (protect the gun)

> **CAUTION**
>
> The gun is at this point still not protected. This means that too high a value for torque/force may cause damage to the gun.

Set Sync check off

In order to be able to close the gun without having performed a tip wear calibration (by running routine `ManServiceCalib` or the instruction `Calibrate \TipChg`), the process synchronization check has to be temporarily disabled.

Set the parameter *Sync check off* (in the type *SG Process*) to *YES* and restart the controller.

> **CAUTION**
>
> Note that `ManServiceCalib` or `Calibrate \TipChg` must not be executed at this stage, since the required tuning to run it not yet is made - this is finalized in *Calibration procedure on page 55*. Running it now may damage the gun.

Set temporary force/torque relationship

Set a temporary force/torque relationship in the type *SG Process*. Ordered force 1 N should give a motor torque of 1 Nm. Note that if the gear ratio in the type *Transmission* is positive, the torque values should be negative.

Set the following parameters, in the type *SG Process*, according to the table and restart the system:

Parameter	Value
Tip Force 1	1
Tip Force 2	2
Motor Torque 1	-1
Motor Torque 2	-2
Number of Stored Forces	2

Increase the torque and measure the force

Use the `SetForce` instruction and a force measurement device to measure the force while increasing the torque.

1. Measure the thickness of the force measurement device and jog the tips to this value. Measure the gap and check that it matches. If not, the gear ratio is probably not correct set up, or the fine calibration is not good enough.

   It is very important that the entered thickness is correct. If the thickness value is too high, the resulting force will get higher due to the extra momentum gained in force control before the tip hits the measurement device. If the thickness value is too low the force will become too low.

Continues on next page

2 Use the `SetForce` instruction with a `forcedata` where torque/force = 1Nm, execute the `SetForce` instruction and measure the resulting force.

   This can be done in manual mode with a hand-held device but take care since the tip force is very high.

3 Increase the torque/force with small steps, 1 Nm, until the maximum allowed force on the tips is reached. This maximum allowed force is given by the gun manufacturer.

   If the maximum allowed force is never reached:

   The torque needed to achieve the maximum allowed force may be higher than the currently maximum allowed torque, defined by *Torque Absolute Max* in the type *Stress Duty Cycle* and *Max Force Control Motor Torque* in *SG Process*. Then these two max torque parameters must be increased (and the system restarted) to be able to reach the maximum force.

4 Set the parameters *Torque Absolute Max* in type *Stress Duty Cycle* and *Max Force Control Motor Torque* in type *SG Process* to the torque giving the maximum allowed force.

5 Restart the controller.

Tip

Create a couple of `forcedata` variables to be used in the instruction `SetForce`. Define `force_1` with force value 1, `force_2` with force value 2, and so on.

Example

Order a gun force of 1 N (actually a torque of 1 Nm) for 2 seconds. The thickness of the measurement tool is in this case 17.6 mm. The plate tolerance is set to 0.

```
VAR forcedata force_1 := [1, 2, 17.6, 0];
SetForce gun1, force_1;
```

More about SetForce

For more information about `SetForce`, see *Application manual - Spot options*.

Problems that might occur

If...	Then...
the gun closes and reopens with error **50021 Joint position error**	the force is probably applied in the wrong direction. Make sure that *Motor Torque 1*, *Motor Torque 2*, etc have the opposite sign compared to *Transmission Gear Ratio*.
the motion speed supervision triggers (error **38104 Overspeed During Teach Mode**) when increasing the force (since this also increases the motor speed during force build-up)	increase *Teach Max Speed DSP* in type *Supervision* with 20% from its original value. This will increase the manual mode speed supervision level in the axis computer. **Note** The manual mode speed supervision level should never be increased more than necessary!

Continues on next page

If...	Then...
the gun is very flexible and error **50021 Joint position error** occurs for higher forces/torques	the position supervision might need to be adjusted. There is a maximum allowed travel distance during force control. This distance is defined by *Max Force Control Position Error* in *Supervision Type*. The default value is 0.03 m. If the gun is very flexible the parameter can be increased carefully in order to allow for a bigger positional drift during force control.
error **50052 Joint speed error** always occurs for higher forces/torques	check that the speed limitation is set to the given default start values (*Speed limit 1*, *Speed limit 2*, *No. of speed limits* in type *Force Master Control*).

6.4 Torque ramp

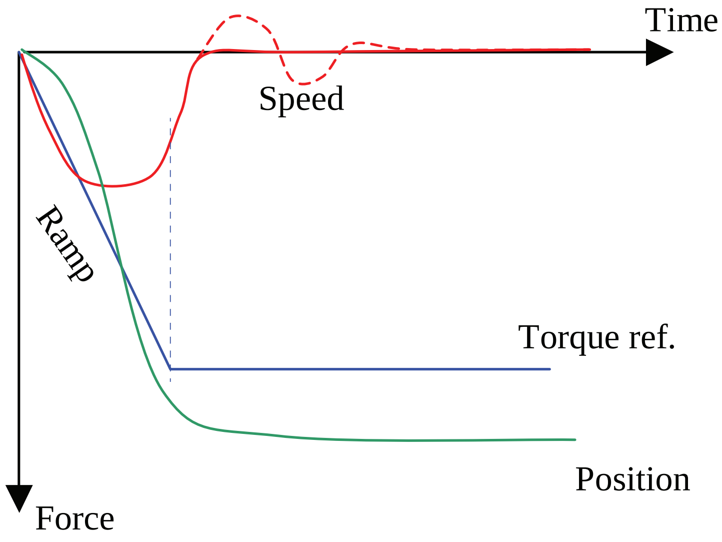
About torque ramp

When the gun is closing and has reached the ordered thickness position with zero speed, force control is activated to build up the gun pressure. The motor torque is then ramped up from the current value to the required torque which then is held constant (until the gun is opened).

The ramping of the torque has an important influence on what the force will look like.

If the ramping is slow, it takes longer time to reach the force and cycle time is lost. Also, the force will become lower because the gun will stick in friction earlier due to the lower momentum during force build-up. There is also a risk for a slip stick phenomena, that is the force fluctuates during welding.

If the ramping is too fast, the force will not stabilize directly and the weld result will be bad due to fluctuation of the force. The force accuracy (repeatability) may also deteriorate.



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The purpose of tuning the torque ramp is to find a fast ramp that gives a high and stable force. A good trade-off strategy is to find a ramp time where the maximum torque is reached between the highest point of the speed and the point when speed is close to zero again, see *Tune the ramp time on page 41*.

Ramp parameters

These parameters belong to the type *Force Master* in the topic *Motion*.

Parameter	Description
Ramp Time	Used to specify how long time the ramp should take to reach its ordered value. This means that the ramping will be steeper for high forces, something that increases the linearity between force and torque (and thereby reduces the calibration effort).

Continues on next page

Parameter	Description
Use Ramp Time	Should be set to *Yes* in order to use the value specified in the parameter *Ramp Time*. If *Use Ramp Time* is set to *No*, the ramping will be specified by the parameter *Ramp when Increasing Force*. This method of tuning the ramp is not explained here, but can be found in *Application manual - Additional axes and stand alone controller*.
Force Detection Min Time	Defines the time in the start before the condition of force ready will be evaluated. Filtered speed is used to detect if the ordered force has been reached. If the gun seems to weld before force is built up, likely due to high friction, it can be a false trigger of low speed in the initial ramp. This value can in those cases be increased.

Make a test program

Make sure the parameter *Use Ramp Time* in type *Force Master* is set to *Yes*.

A force measurement device that displays the force curve versus time is useful, but not a demand for this tuning.

Create a routine with a `SetForce` instruction.

Recommended values in `forcedata` used by `SetForce`:

`forcedata` component	Recommended value
`tip_force`	70% of the maximum allowed torque (torque is still equal to force)
`force_time`	for example 1 or 2 s
`plate_thickness`	thickness of the force measurement device. Use zero if there is no force measurement device.
`plate_tolerance`	0

Example

Order a gun force of 7 N (actually a torque of 7 Nm) for 2 seconds. The thickness of the measurement tool is in this case 17.6 mm. The plate tolerance is set to 0.

```
VAR forcedata force_7 := [7, 2, 17.6, 0];
SetForce gun1, force_7;
```

Run the program

Run the program and check the Test Signal Viewer curves.

Fine adjust the thickness

If *plate_thickness* is given a correct value or too high a value, the torque should be equal or less than *low_speed_friction* for the gun (calculated in *Identify the friction on page 34*) when the torque ramping is started. Decrease the thickness carefully until the torque starts to increase.

If the torque is higher than *low_speed_friction* when ramping is started, this indicates a non zero force between the tips. Increase the thickness carefully until the condition is met.

Continues on next page

Tune the ramp time

Tune the ramp time by adding the instruction `STTune` in the beginning of the test program.

The aim is to ramp the torque as fast as possible without getting too much overshoot in speed (and force). A small speed (and force) overshoot is acceptable. See the example below.

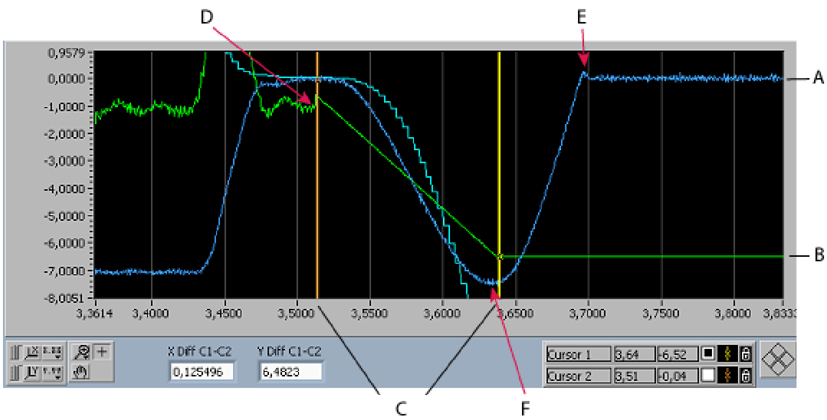
The default value of the ramp time is 0.07 s.

The goal is to find a ramp time where the maximum torque is reached between the highest point of the speed and the point when speed is close to zero again. This is expected to be reached within 200 ms for most servo guns.

Example

In this example the ramp time is tuned to it's shortest time, where the maximum torque is reached when the speed is at it's highest point. However, this may cause the gun to be unstable.

It is therefore recommended to increase the ramp time to find a ramp time where the maximum torque is reached between the highest point of the speed and the point when speed is close to zero again, see *About torque ramp on page 39*.



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A	speed
B	torque_ref
C	Markers placed at the beginning and end of the ramp. The distance between these are shown in **X Diff**, showing a ramp time of 0.125 s.
D	Initial torque when the the torque ramp is started. It should be <= *low_speed_friction* if the programmed plate thickness is correct.
E	Speed overshoot, proportional to the force overshoot.
F	Peek speed. The maximum speed during force control. Tuning is optimal if it occurs in the end of the torque ramp.

Example of how to use STTune

Tune the torque ramp time to 0.12 seconds.

```
STTune gun1, 0.12, RampTorqRefClose;
```

Continues on next page

Set Ramp Time

Update the parameter *Ramp Time* in type *Force Master* with the optimal tuned value found and restart the controller.

6.5 Find the maximum torque (protect the gun) a second time

Why do this again?

Now the maximum torque has to be verified again since the relation between force and ramp time has an impact. This means that the gun now has a new relation between torque and force.

Note

This is temporarily done and has to be recalibrated again after tuning of speed limitation, when the gun is tuned in terms of performance and accuracy.

Measurement procedure

Follow the procedure described in *Increase the torque and measure the force on page 36*.

6.6 Speed limitation

Purpose of speed limitation

There is an active limitation of the speed during force control. The speed limitation has two purposes:

- It prevents an uncontrolled acceleration if the programmed thickness is too high (or if a tip is missing). The speed will be limited to a configured (tuned) level and the gun will travel smoothly until tip contact is obtained and the force is reached.
- It greatly improves the accuracy of the tip force. It minimizes the error in force when a bad thickness value is given.

About speed tuning

The tuning idea is to find the maximum speed in force control when the thickness is accurately programmed. This "natural" speed multiplied with a factor will then define the speed limitation level for that torque (force). The "natural" speed is proportional to the programmed torque, higher torque allows for higher speed (and larger arm deflection).

The speed limitation level, defined by *Speed limit 1* and *Speed limit 2*, is a function of the programmed torque, defined by *Torque 1* and *Torque 2*.

Set initial speed limits

In this procedure, two speed limit levels are defined (*No. of Speed Limits* = 2) but only the second is tuned. The first speed limit is set to "zero" speed for a programmed "zero" torque. The speed limit level is interpolated between these two levels.

Make sure the following parameters are set:

Type	Parameter	Value
SG Process	Close Position Adjust	0
Force Master Control	No. of Speed Limits	2
Force Master Control	Kv 1	1
Force Master Control	Kv 2	1
Force Master Control	Speed Limit 1	0.001
Force Master Control	Speed Limit 2	300
Force Master Control	torque 1	0.001
Force Master Control	torque 2	10

Tune speed limits

Create a routine with a `SetForce` instruction.

Recommended values in `forcedata` used by `SetForce`:

`forcedata` component	Recommended value
`tip_force`	Maximum allowed torque (torque is still equal to force)
`force_time`	For example 1 or 2 s

Continues on next page

`forcedata` component	Recommended value
`plate_thickness`	Gun position when tips are in contact. No sensor is needed.
`plate_tolerance`	0

Example

Order a gun force of 10 N (actually a torque of 10 Nm) for 2 seconds. The plate thickness is set to 0. The plate tolerance is set to 0.

```
VAR forcedata force_10 := [10, 2, 0, 0];
SetForce gun1, force_10;
```

Run the program

Execute some closings and analyze the Test Signal Viewer curves.

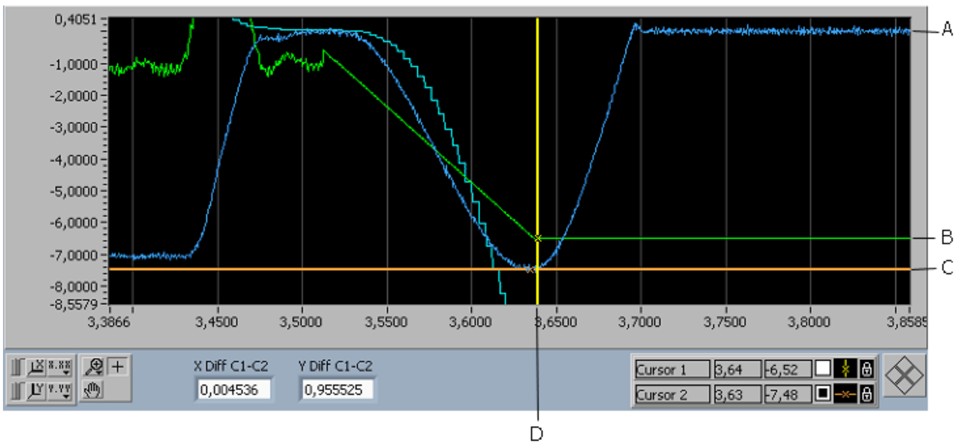
Fine adjust the plate thickness, see *Fine adjust the thickness on page 40*.

The speed seen in the Test Signal Viewer will have two maximum values. The first one is usually the largest one and corresponds to the speed when moving to contact position. The speed value we need for the tuning is the second top, which corresponds to the speed when the gun tips are in contact (= the natural speed).

Set final speed limits

Change *Speed Limit 2* in type *Force Master Control* to the found value of the natural speed multiplied with 0.8. Change *torque 2* to the programmed torque value (= max torque).

Example



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A	speed
B	torque_ref
C	Cursor 2, indicating the highest speed before the tips are in contact (natural speed). Since the scale of the speed is 0.1, the cursor value -7.48 represents a speed of -74.8 rad/s.
D	Cursor 1, indicating the highest torque (-6.52 Nm).

Given the values shown in the picture, set the following values:

- Set *torque 2* to the highest torque, 6.52.

Continues on next page

- Set *Speed Limit 2* to 0.8 * natural speed = 0.8 * 74.8 = 60.

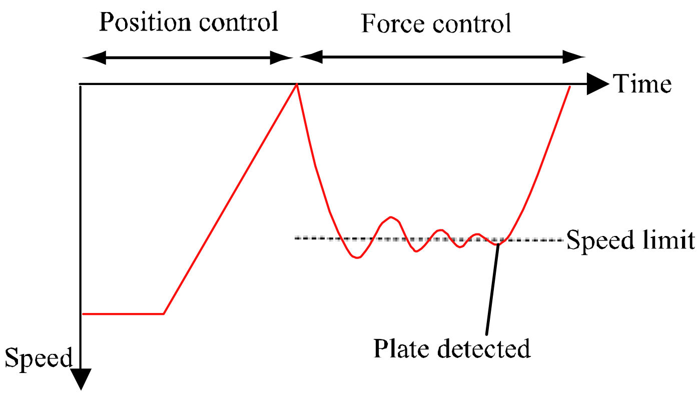
6.7 Kv for speed limitation

About Kv

Now motion control during speed limitation should be tuned.

With each speed limitation level, defined by *Speed Limit 1* and *Speed Limit 2*, there is a corresponding *Kv 1* and *Kv 2*. *Kv* defines the amplification of the speed during speed limit control. *Kv* has no influence if the speed during force control is lower than the speed limit.

A low value will make the speed limitation slower and the actual speed will reach a higher value before the speed is limited. Too high a value will cause unstable control with oscillating torque and speed.



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The *Kv* parameters should be adjusted so that the overshoots get optimized.

It is usually not necessary to change this parameter from the default value 1, except for a gun with a high inertia that gains a higher momentum during force control. In this case *Kv 1* and *Kv 2* can be set up to 2 or more.

Tune Kv

Make a test program starting with an `STTune` instruction for tuning *Kv*.

Add the instruction `SetForce` with thickness value 5 mm. Use no plates between the tips in order to start force control and reach the speed limit level before obtaining tip contact.

Code example

```
VAR forcedata force_10 := [10, 1, 5, 0];
STTune gun1, 2, Kv;
SetForce gun1, force_10;
```

Set Kv parameters

Set both the parameters *Kv 1* and *Kv 2* to the value found during the tuning.

Restart the controller.

6.8 Close Position Adjust

Define Close Position Adjust

The parameter *Close Position Adjust* belongs to the type *SG Process* in the topic *Motion*.

1. Set *Close Position Adjust* to 0.001.

   This will introduce a constant "programming error" of +1 mm for every gun closing. The adjustment improves the force accuracy for negative thickness errors (too low values for programmed thickness). The adjustment also increases the force due to the higher momentum when the tips get in contact with the plates. Therefore, force calibration has to be redone.

   If the plate tolerances is extra high for a certain application, *Close Position Adjust* could be increased further in order to improve the force accuracy. For example, 0.002 m may give a better result.
2. Restart the controller.

6.9 Find the maximum torque (protect the gun) a third time

Why do this again?

Now the maximum torque has to be verified again since the relation between force and speed limitation has an impact. This means that the gun now has a new relation between torque and force.

Measurement procedure

Follow the procedure described in *Increase the torque and measure the force on page 36*.

Problems that might occur

If...	Then...
error **50052 Joint speed error** always occurs for higher forces/torques	the speed supervision might need to be adjusted. There is a maximum allowed speed overshoot during force control. This speed is defined by *Max Force Control Speed Error* in *Supervision Type*. Default value is 1.4 and corresponds to 140% of the speed limitation. The parameter can be increased carefully in order to allow for a bigger speed error during force control. However, the problem is preferably solved by improving the speed limitation *Kv* tuning in order to reduce the speed overshoot.

6.10 Force calibration

Run ManForceCalib

Use the service routine `ManForceCalib` and a force measurement tool to calibrate the force/torque relation according to the following procedure:

1. From the program editor on the FlexPendant, select **Debug** and tap **Call Service Rout.**
2. Tap **ManForceCalib** and then **Go to**.
3. Press the Start button on the controller.
4. Tap **1** and set up force calibration data:
    - at least two calibrations
    - the maximum torque
    - the thickness of the force measure tool
    - a time long enough to be able to measure the force (e.g. 2 s)
5. Tap **2** and measure the force for each gun closing during the calibration.

Correctly defined force

The gun is now calibrated and the force shall from now on be set in Newton.

This means that in every `SetForce` instruction the valid unit is now N.

7 Accelerations

7.1 Acceleration settings

Acceleration definitions

The movement acceleration is limited by the maximum allowed torque defined by *Torque Absolute Max*. The accelerations is also limited by the friction level.

Acceleration is defined by the following parameters in type *Acceleration Data*:

Parameter	Description	Unit
Nominal Acceleration	Defines the acceleration of the gun arm	m/s^2
Nominal Deceleration	Defines the deceleration of the gun arm	m/s^2

It is recommended to use the same value for *Nominal Acceleration* and *Nominal Deceleration* although it often is possible to have a slightly higher value of *Nominal Deceleration* since the friction always helps to decelerate the movement.

Tuning accelerations

Tune the accelerations in order to minimize the movement time without reaching the torque limit.

Run long movements back and forth with full speed using two `IndGunMove` instructions. Auto mode is required to reach max speed. Note that synchronous movements like `MoveJ` or `MoveL` should not be used since these movements give a lower acceleration.

Check in Test Signal Viewer that the torque during the movement never reaches the torque limit curves.

Increase/decrease *Nominal Acceleration* and *Nominal Deceleration* in type *Acceleration Data* so they almost reach the torque limits.

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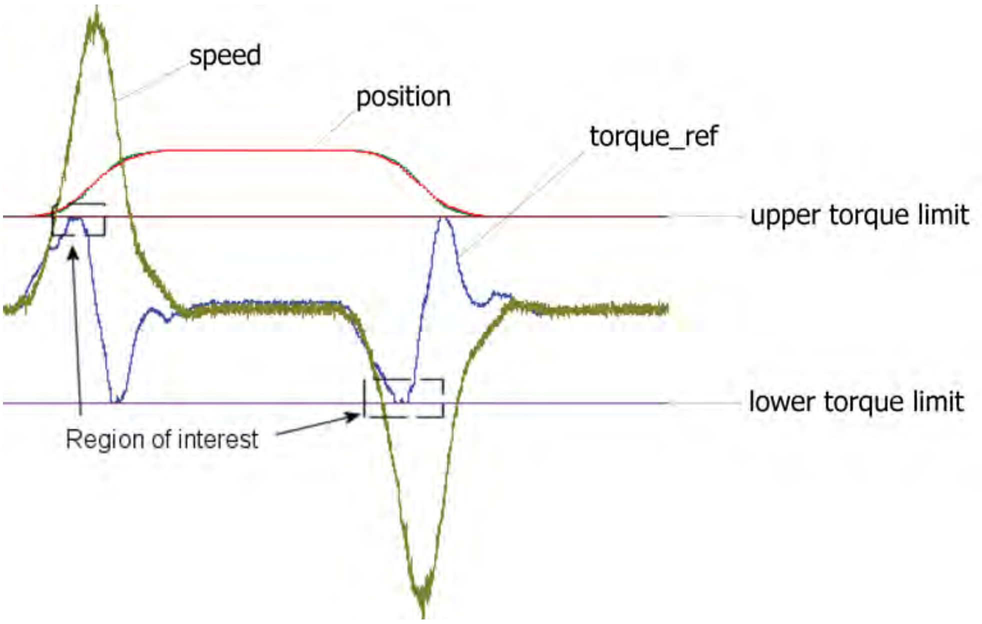
Example of too high *Nominal Acceleration* (because torque_ref reaches the torque limit):



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Note

This tuning should be done with a cold motor since the friction of the gun is reduced with temperature.

Reducing the acceleration to about 70% of its maximum value will create a buffer to protect the system against unnecessary joint speed errors.

Leave independent mode

Execute instruction `IndGunMoveReset` to leave independent mode.

8 Calibration routine

8.1 RAPID instruction Calibrate

Overview

This tuning will make the `Calibrate` instruction work properly.

The `Calibrate` instruction is used to manage the tip wear and the tip position when the tips are exchanged (`\TipChg`) and while they are worn down (`\TipWear`).

CAUTION

Do not execute a `Calibrate` instruction (or `ManServiceCalib`) until all necessary parameters have been defined. Follow the procedures in *Calibration procedure on page 55*.

What happens when Calibrate \TipChg is executed?

`Calibrate \TipChg` updates the tip contact position of the servo gun and the tip wear is set to zero.

When...	...then...	Involved parameters
`Calibrate \TipChg` starts to execute	the gun makes a slow movement to carefully bring the tips to contact. The torque during the movement mainly originates from the low speed friction of the gun.	The movement speed is defined by *Collision Speed*, type *Force Master*.
tip contact is established	the torque starts to increase.	
the torque exceeds *Collision Alarm Torque*	tip contact position is detected.	*Collision Alarm Torque*, type *Force Master*.
tip contact position is detected	the position of the gun is equal to the current deflection of the gun arm. The contact position without force is accurately updated by the system.	The deflection is identified and stored in *Collision Delta Position*, type *Force Master*.
the initial closing is finished	a fast second closing is done.	The obtained force in the second closing equals *Calibration Force Low*, type *SG Process*. The force is held a time defined by *Calibration Time*, type *SG Process*.

Continues on next page

What happens when Calibrate \TipWear is executed?

`Calibrate \TipWear` updates the tip contact position of the servo gun and the tip wear is updated. Also, the deflection of the arm is verified.

When...	...then...	Involved parameters
`Calibrate \TipWear` starts to execute	the gun makes a fast closing.	The closing force is defined by *Calibration Force Low*, type *SG Process*. The force is held for a period defined by *Calibration Time*, type *SG Process*.
the initial closing is finished	a fast second closing is done.	The closing force is defined by *Calibration Force High*, type *SG Process*.

8.2 Calibration procedure

Define the calibration routine parameters

SG Process

Define the following *SG Process* parameters:

Parameter	Value to set
Calibration Force High	The force for a welding process for this specific gun. Value in N. This should be at least 70% of the guns maximum allowed force.
Calibration Force Low	The force corresponding to the torque 2 * Low_speed_friction (calculated in *Identify the friction on page 34*). Value in N. Use `STCalcForce` to calculate the force corresponding to a known torque. *Calibration Force Low* must be less than 80% of *Calibration Force High* and more than 20% of the maximum allowed force but at least 1300 N.
Calibration Time	0.5 s

Example of how to use `STCalcForce`. In this example 2*Low_speed_friction = 1.2 Nm:

```
VAR num force;
force := STCalcForce("RGUN_1", 1.2);
```

For more information about `STCalcForce`, see *Technical reference manual - RAPID Instructions, Functions and Data types*.

Force Master

Define the following *Force Master* parameters:

Parameter	Value to set
Collision Alarm Torque	'3 to 4' * Low_speed_friction (calculated in *Identify the friction on page 34*). Value in Nm. If the maximum force of the gun is less than 3300 N, the value must not be lower than a torque corresponding to 30% of *Torque Absolute Max*, type *Stress Duty Cycle*. If the maximum force of the gun is more than 3300 N, the value must not be lower than a torque corresponding to 1000 N (= `STCalcTorque("gun",1000)`) **Note** Note that this value is is different for c- and x-guns. It is recommended to check this value when servicing the gun.
Collision Delta Position	0. Value in m. The correct value is identified later.

Restart controller

After updating the parameters, restart the controller in order for the changes to take effect.

Identify Collision Delta Position

1 Execute the instruction `Calibrate \TipChg`
2 Jog the tips to contact without force.

Continues on next page

The position on the FlexPendant will now have a small positive value (+1 to +5 mm). The reason for this is that the position of the gun when *Collision Alarm Torque* was reached now has become the new zero position. The "position error" originates from the flexion of the gun arm until *Collision Alarm Torque* is reached.

3. Update *Collision Delta Position* in type *Force Master* with the position displayed on the FlexPendant (in meters).

   This will ensure that you always have a correct zero position after `Calibrate \TipChg`.
4. Restart the controller.
5. Execute the instruction `Calibrate \TipChg`
6. Verify that the position displayed on the FlexPendant is the same as the physical position.

Verify Calibration Force Low

Execute the instruction `Calibrate \TipWear`

Verify that the speed during force control at the first gun closing (using *Calibration Force Low*) becomes stable at zero before the gun is opening. If not, increase the *Calibration Time* in type *SG Process*. Too short a *Calibration Time* may decrease the accuracy of the tip wear value.

Set Sync Check

Set the parameter *Sync Check Off* in type *SG process* to *No*.

This will protect the gun from being closed (with `SpotL`/`SpotJ` or `SetForce`) without having performed an initial tip calibration (by running `ManServiceCalib` or executing the instruction `Calibrate \TipChg`).

If revolution counters are lost or if a Fine Calibrate is performed, a calibration with `ManServiceCalib` or `Calibrate \ToolChg` is required before a new gun closing is allowed.

Tuning ready

All necessary gun tuning is now done.

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