DELTA – Robot with Parallel Kinematics

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Michal Holub
Brno University of Technology

DELTA - robot with parallel kinematics

M. Opl, M. Holub, J. Pavlík, F. Bradáč, P. Blecha, J. Kozubík, J. Coufal

Brno University of Technology, Technická 2896/2
Brno, 616 69, Czech Republic

Abstract

A complex solution of a design of the DELTA type robot, i.e. the robot with parallel kinematics, is described in this paper. The project ensued from cooperation with the company Dyger, s.r.o., with the objective to develop a robotic device suitable for high-speed handling of small objects and applicable in many industrial configurations. The task was not only to design the mechanical part of the robot that would work together with the provided hardware and software, but also to develop our own algorithms for calculations of the target positions, singular positions of the mechanism etc.

1. Introduction

This project has been motivated by a requirement from industry. Our department received a proposal for possible cooperation in development of the robot with parallel kinematics – DELTA type robot. The company Dyger, s.r.o., is an exclusive representative of the company Beckhoff and has at its disposal the recently-released data library for control of robotic appliances with parallel kinematics. Hence, we attempted to make use of these new possibilities and to develop an affordably priced DELTA robot which could be further offered for solutions of specific industrial applications.

As the supplied software is not an open source software and it is not possible to simply verify if the mathematical description of the mechanism are valid, we proceeded to develop our own algorithms for calculations of position, speed, acceleration and, first of all, for calculation of the mechanism's working space and equally important singular positions. Our objective was also to verify the mathematical apparatus used in the supplied software [1].

2. Kinematic analysis of DELTA robot

The kinematic configuration of the DELTA robot presents one of the more simple types of parallel structures. This is achieved through implementation of three parallelograms, ensuring mutual parallelism of the stationary base and the moving platform [2].

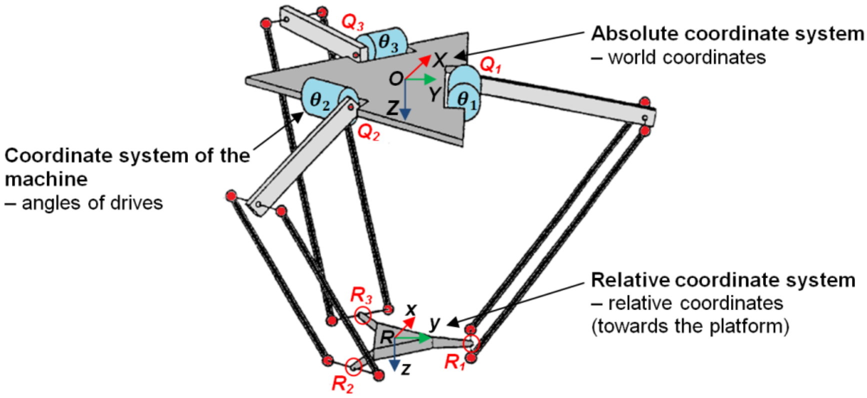

Fig. 1. Kinematic scheme of DELTA robot [5]

Based on an analysis of the individual kinematic links and their degrees of freedom (DOF) it is possible to calculate the total number of DOF of the mechanism with the equation (1).

$$F = b(n - g - 1) + \sum_{i=1}^{g} f_i - f_{id} + s \tag{1}$$

Where b – number of DOF in space, n – number of elements, g – number of joints, f_i – DOF of i-th element, f_{id} – number of identical DOF, s – number of passive joints.

After substitution, the total number of DOF equals three. These DOF represent only translational motions of the platform, hence the absence of rotary motions ensures the desired parallelism.

Another complex parameter affecting applicability of a robot in a specific industrial configuration is the size and shape of the working space. However, the working space is an unknown quantity, ensuing from the construction and therefore also from the individual partial parameters of the mechanism. To delimit the working space, it is first necessary to define these parameters. It is mainly the geometric parameters (lengths of the arms, positions of joints etc.) shown in Fig. 2.

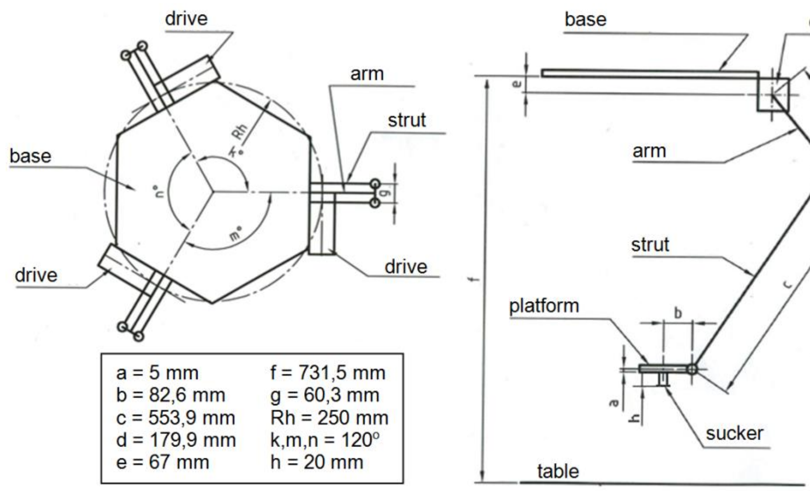

Fig. 2. DELTA robot parameters definitions

To determine the working space size parameters, we have used a problem from indirect kinematics, following from the geometric approach to the whole solution. The principle is displayed in Fig. 3. This method was chosen because it is simple, easy to understand and the calculations can be realized with high efficiency.

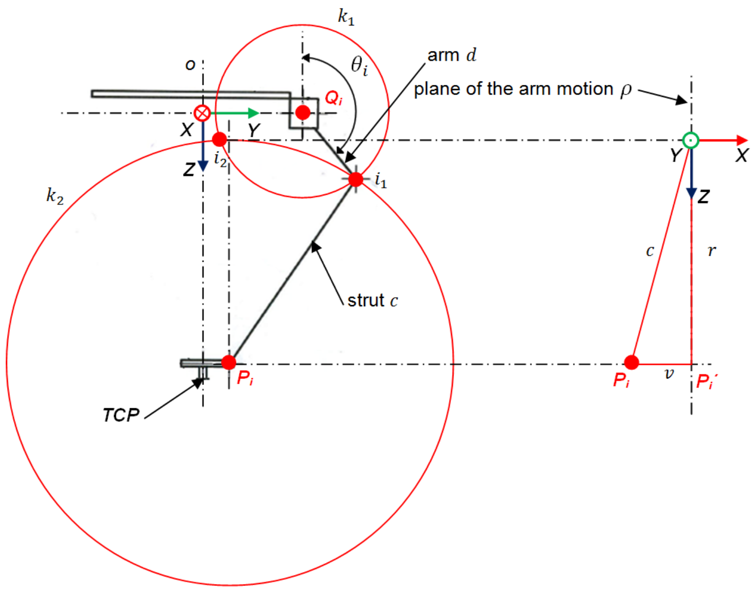

Fig. 3. Geometric approach to solution

$$\boldsymbol{A} = \boldsymbol{i}_1 \quad (2)$$

$$\boldsymbol{B} = [-1,0] \quad (3)$$

$$\boldsymbol{\theta}_i = arccos((\boldsymbol{A} \cdot \boldsymbol{B})/(|\boldsymbol{A}| \cdot |\boldsymbol{B}|\,)) \quad (4)$$

The results of this geometric solution are the desired angles of the arms Θ_i. The calculated angles were further used for determination of the working space. A numerical incremental approach was applied to calculate the angles Θ_i on the basis of the predefined criteria in a predefined space and their relevance was assessed (solutions i_1 and i_2 are shown in Fig. 3). The final shape and dimensions of the working space can be seen in Fig. 4.

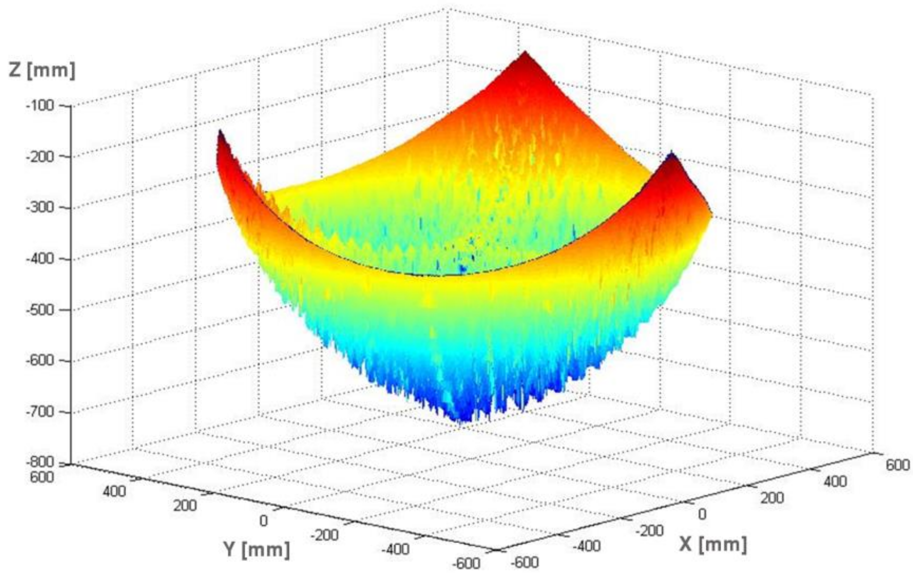

Fig. 4. Working space of DELTA robot

This step has served for definition of the size and shape of the DELTA robot working space from the parameters according to Fig. 2. Specific requirements on position optimization of the TCP (TOOL CENTER POINT) can be achieved through changes of the individual parameters. Regarding the concept of parallel mechanisms it is necessary to take into account the possibility of existence of singular positions, which, when reached, cause loss of power transmission or loss of some DOF. From the aspect of practical use of the device, these positions are undesirable. For this reason it is necessary to examine all relevant singular positions of the mechanism so that restricting criteria of the positioning could be set. In our case, the geometric approach was also applied. The result is displayed in Fig. 5 right. [3]

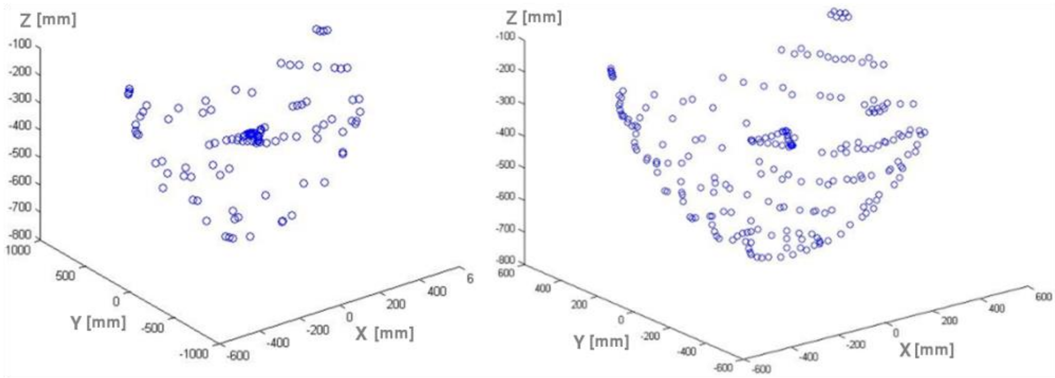

Fig. 5. Singular positions – Jacobian verification on the left

To verify our presumptions and correctness of the calculation algorithm, we have performed a check calculation with a Jacobi determinant according to López [4]. The obtained results have verified sufficient accuracy of the approach used in our work for this specific type of kinematics.

3. Design solution

The DELTA type robots with the parallel mechanism are characterized with high dynamics of the end effector (TCP). This comes together with the requirements on minimum weight of the moving components, sufficiently sized drives including transmissions, stiffness of the individual components and mainly minimum backlash in the joint couplings.

The selected type of drive (a servo motor with a planetary transmission) with the maximum output torsion moment of 90 Nm provides a sufficient potential for development of a highly dynamic device. In accordance with this criterion, the components and their material, directly affecting the overall TCP dynamics, were suitably selected. For most of the components, aluminium alloy was chosen as the construction material with suitable mechanical properties. The struts were made of a composite material on the basis of carbon fibres due to its more suitable weight/stiffness ratio.

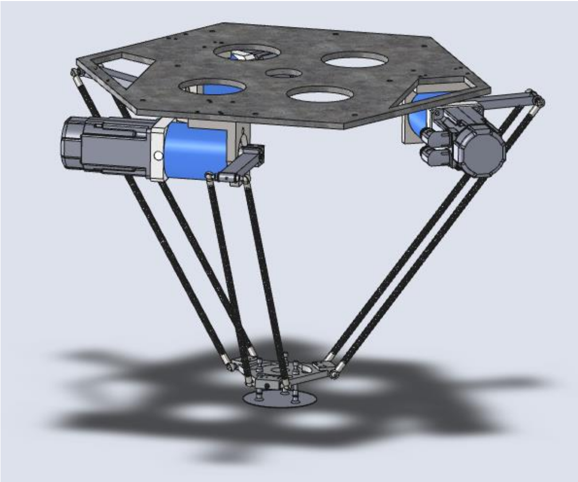

Fig. 6. 3D-model of DELTA robot

For the purpose of experimental tests focused on accuracy and durability of joint couplings, several variants of the solution were proposed. They are built of components readily available on the market. Fig. 7 right shows a classic design solution employing a ball joint to realize the joint couplings. A drawback of this solution is the need to exert retention force; in this case it is realized by springs between the individual struts.
The second variant of solution is realized with the components produced by the IGUS company (Fig. 7 left). The joint is made in the form of two mutually perpendicular rotary couplings ensuring sufficient DOF. An advantage of this solution is that mutual preloading of the rods is not necessary. A drawback lies in higher complexity due to higher number of components needed to realize this link and lower resistance to possible accidents [6].

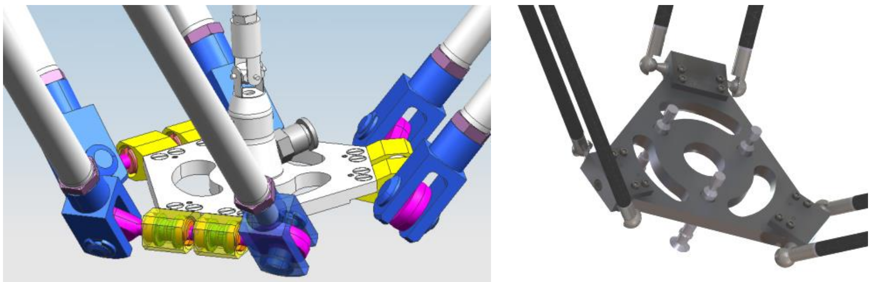

Fig. 7. Constructional variants of the joint couplings

4. Conclusion

Based on the described proposals, the DELTA robot prototype has been built that is currently being subject to intensive experimental tests focused on improvement of the accuracy and dynamics of the mechanisms and also on durability of the individual components.
These experiments have sufficiently verified the control system functions including the Beckhoff company library, as well as the theoretical knowledge regarding the working space size and singular positions of the DELTA robot.
The obtained results were presented in an exposition of the Dyger company at the AMPER international fair trade which took place in Brno in spring 2011.
Another task within the project, which is still being worked on, will be rotation of the end effector. This additional construction component of the DELTA robot seems to be essential for most of the industrial applications. Also, a suitable user interface for control of the robot functions will be supplemented in cooperation with the Dyger company. The objective is to design a marketable product which could be offered for applications in industry (see Fig. 8).

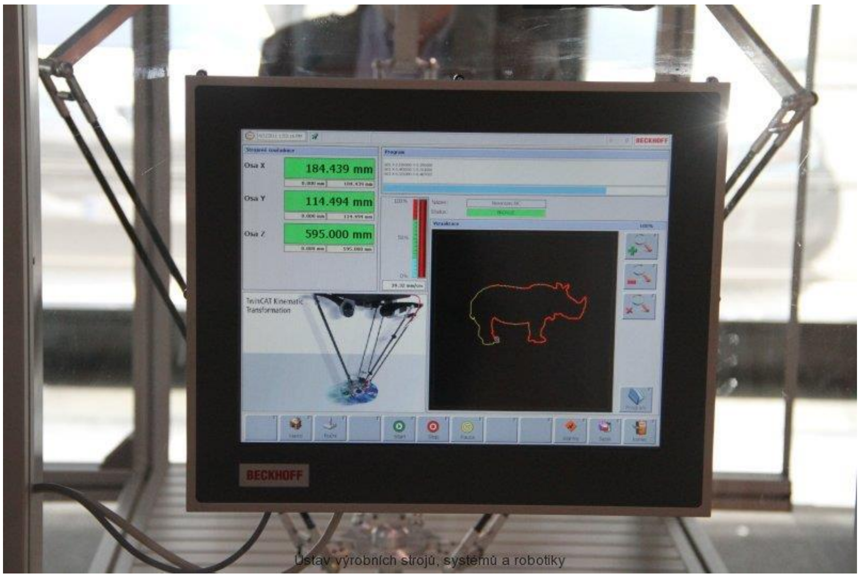

Fig. 8. DELTA robot control system touch panel

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