DEVELOPMENT OF FIRST AND SECOND GENERATION OF ROTARY MODULE WITH AN UNLIMITED DEGREE ROTATION

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The article deals with the development and changes that have been made to the rotary module with an unlimited degree rotation of first and second generation called URM. The proposed solution of module is suitable for machines and equipment that require unlimited freedom of rotation. URM is based on a modular principle. At first part the article describes design and development of the module prototype, its construction and the principle on which it works. After production of the functional module and detection of shortcomings we started development of the second generation module. The second generation of URM was based on knowledge gained in working on the prototype and its task was to improve the existing module and remove shortcomings of the first generation. Then the article describes adjustments that have been made to produce the second generation module and its goals, which are reduction of clear height of the module and reduction of weight. The main element to achieve these goals was to replace the original angular contact bearings with igus plain bearings.

KEYWORDS

Modular principle, rotary module, URM, bearing

1 INTRODUCTION

The replacement of human labor by manipulators or robots has become very popular nowadays. It is mainly about handling heavy objects or fast repeating operations. In order to be effective, such a manipulator should have at least five degrees of freedom [Malega 2007]. The rotary module with an unlimited degree rotation (URM) offers the ability to assemble machines with different movement options and degrees of freedom from either the same module type or slightly modified modules. These aspects have a beneficial effect on the construction of the serial kinematic structure, in particular on the coverage of wider range of working space and on the operating capacity of the manipulator. The URM module is designed for machines and equipment that require unlimited rotational motion to perform their operations. The use of this rotary module is envisaged for industrial robots and manipulators with lower movement dynamics or possibly for special machines with special focus [Svetlík 2018]. After making certain adjustments, the module could also be used in production technology. In particular, the URM 01 module has the ability to rotate freely. To make the module even more usable in companies, we have started developing the second generation module URM 02, which aims to overcome the shortcomings of the first module prototype.

2 UNIVERSAL ROTATION MODULE 01 (URM 01)

Universal Rotary Module 01 (URM 01) is a rotary module with an unlimited degree of rotation. This solution is suitable for machines and equipment that require unlimited freedom of rotation for their operation. The URM 01 is structurally and conceptually based on a modular principle, which makes it possible to assemble different machines and devices using one type of module (Fig. 1). If, for some reason, this solution does not suit or it is necessary to build another machine with different characteristics, we can rebuild the original solution and use modules for other applications because of modularity. The proposed machines and devices can achieve different possibilities of movement in space and degrees of freedom by means of unrestricted rotation of two adjacent modules, which are interconnected by movement coupling [Svetlík 2010].

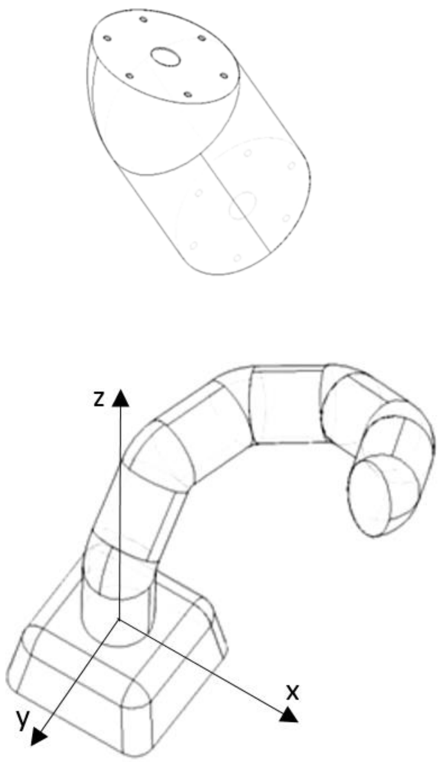

Figure 1. The concept of the rotary module URM in kinematic structure

The construction of URM 01 is designed so that no part can prevent unlimited rotation of the modules. For this reason, all components (motor, gearbox, batteries, etc.) are located inside the module body (Fig.2). This location protects the components from external influences [Štofa 2017]. The result of this solution is a modular system that allows to produce modular robots and manipulators that are assembled from the same or slightly modified URM 01 modules with an unlimited rotary motion. Machines and equipment made from these modules are designed to ensure the best working range and also to achieve the desired points in workspace. Each module is equipped with a Foulhaber DC servomotor located in the center of the module body. The engine is equipped with an incremental encoder Faulhaber, which can sense 102400 positions per revolution. The engine output is equipped with a Faulhaber reducer and an electric brake located behind the reducer. To keep the module running after a power failure, it is equipped with LiPol 4in1 batteries. The whole module is controlled by PID regulation of the servomotor. The rated rotary universal module speed is 30 rpm.

The exact description of used components:

- DC servomotor faulhaber 3863 012C, 204W, 12V, 85% efficiency,
- incremental encoder faulhaber IE2-512,
- faulhaber reducer 38A, 200: 1, 20Nm,
- Sensor resolution 102 400 positions to full turn,
- output nominal speed 30 full turn / min,
- electro brake 6W, 12V, 80Nm behind reducer,
- balancing accumulator LiPo4in1, 14.8V,
- Current drain max. 17A,
- PID control of servomotor.

3 UNIVERSAL ROTATION MODULE 02 (URM 02)

When designing the URM 01 module, the aim was to maintain a balance between module height and width. This implies that the height of the module should be the same as its width if possible. The weight of one module should be as low as possible. These conditions were intended to allow good handling of the modules when assembling the manipulator [Kuznetsov 2018]. URM 01 did not fulfil these conditions as expected, so we focused on them in developing the second generation URM 02.

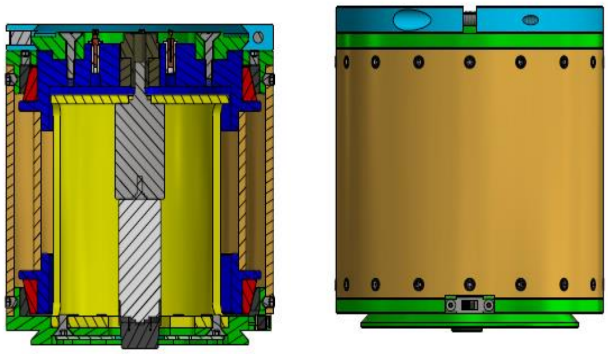

Figure 2. 3D model of URM

Individual module changes consisting of weight reduction, clear height reduction and maximum module stiffness are described in the this chapter. The total weight of one URM 01 module without internal electronics (battery, control board) is 3 302 kg. Bearings account for 32% of the weight.

Figure 3. Second generation of URM

The weight of one bearing is 0.541 kg and there are two such bearings in each module. Due to the high weight of the bearings and the problems with defining the bearing preload, we decided to replace these large and heavy bearings with another alternative, which should bring the desired reduction effect. As an alternative, we have chosen igus® plain bearings. Igus® offers a wide range of plain bearings with different properties and applications. Our priority was heavy-load plain bearings. The choice was made between three bearing types, iglidur® G, iglidur® Q and iglidur® Z. Their mechanical properties are described in Table 1.

Mechanical properties	iglidur® G	iglidur® Q	iglidur® Z
E-bending module	7.800 MPa	4.500 MPa	2.400 MPa
Bending strength	210 MPa	120 MPa	95 MPa
Compressive strength	78 MPa	89 MPa	65 MPa
Maximum recommended surface pressure	80 MPa	100 MPa	150 MPa

Table 1. Mechanical properties of bearings

We decided to use iglidur® G plain bearings for our application. The reason why we decided to use these bearings is mainly their mechanical properties and lower price of these bearings. With their mechanical properties, iglidur® G plain bearings are absolutely sufficient for application in URM module. The second reason is the price of bearings, the price of iglidur® G is 16 €, the price of the next two is rising rapidly: iglidur® Q - 37.33 € and iglidur® Z - 48.57 €. If testing proves that iglidur® G plain bearings are not sufficient, there will still be room for the use of higher bearing classes, but with higher investment costs. Iglidur® G is characterized by endurance of extremely high loads, low to medium circulation speeds and simple rotational movements. The specified bearing characteristics meet our requirements exactly for use in the URM 02 module. The bearing is F-shaped with the dimensions in Table 2.

Inner diameter	85 mm
Outer diameter	90 mm
Flange diameter	98 mm
Bearing width	98 mm
Flange thickness	2,5 mm

Table 2. Bearing dimensions

The weight of the new bearing is 20 g, which is the difference from the original bearing 521 g. By replacing the bearings, we reduced the weight of the module from the original 3,302 kg to 2,260 kg.

Figure 4. Old bearings used in URM 01 module

The weight reduction of the module has a positive effect on the dynamics of movement of assembled devices, as well as on the positioning accuracy, load of the end elements or elastic deformation. It should be noted that the weight of 2 260 kg is not final. By replacing the bearings it is necessary to modify the individual components of the module, whereby the total weight of the module can be reduced. The idea is to build a module weighing 1.5 kg [Štofa 2017]. The main idea in the design of the URM 01 module was that its height would be the same as the width for better reconfiguration. The smaller the module, the less equipment we can build. If we need larger dimensions of the resulting machine, just insert a jumper between the modules. New bearings are shown in Figure 5 [Svetlík 2018].

Figure 5. New bearings iglidur® G used in URM 02 module

4 PURPOSE OF URM MODULE

Modular machines with unconventional solution also include the proposed modular system, for which a basic building module with rotary motion is developed together with submodules, which together create a modular system usable for handling operations and after the development and modification also technological operations. Motion analysis of the virtual URM model is an input into the study of a new kinematic arrangement of a homogeneous series of kinematic structures [Božek 2018]. The first results of the simulation indicate the suitability and usability of such an arrangement in the structure. The main advantage is the construction simplicity, large spatial reach, variability and flexibility of modular combinations and thus many possibilities of arrangement of the kinematic structure. Further development assumes the necessity to unify the rotary modules and their development into structural interconnectable modular series. The use of wireless technologies is foreseen for the transmission of energy and data quantities. This solution leads to the negation of the rotation constraint of the individual base modules and thus to the elimination of this constraint in the solutions currently on the market [Baron 2016]. The use of the above mentioned rotary module design is envisaged for robots with lower movement dynamics, after suitable modification also in production machines with special focus, eventually in special applications .

Figure 6. Assembly of functional prototype components of URM 02

5 CONCLUSIONS

The Universal Rotary Module (URM) is a rotary module with an unlimited degree of motion rotation. The main use of the URM module is the creation of serial kinematic structures. The number of degrees of freedom depends on the number of interconnected modules. The URM 01 module is the first prototype and its production enabled testing of the module. On this prototype deficiencies have been identified that need to be removed. When developing the second generation module called URM 02, these deficiencies have been eliminated as much as possible. We focused mainly on weight reduction and reduction of dimensions of URM 02, which were the main ideas in the development of URM 01. The main change of the URM 02 module is the replacement of bearings, which allowed further tuning of the module. The original angular contact bearings were replaced with iglidur® G plain bearings. This major change has led to a reduction in module weight from the original 3.302 kg to 2.260 kg, which is not the final weight, as other module components have also been changed, making the module even simpler and easier. Changing the bearings also change the module length from 176 mm to 108 mm. As a result, we managed to build this module as low as possible, which was also one of the goals. With these changes, we can create smaller kinematic chains and cover a wider range of workspaces.

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