

SECONDARY PROPOSAL OF COUPLING MECHANISM ROTATION UNIVERSAL MODULE

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The authors focus on the adjustment of coupling mechanism Rotation Universal Module that offers unlimited rotation of movement. The module has been designed to achieve different kinematic structures by use of an identical module. A unique interface mechanism, which has undergone several modifications and amendments, has been designed for this module. The main objective is to achieve efficient and more secure initial solution of connecting two adjacent modules. The amendments of primary solution that will contribute to achieve desired outcomes and smooth functioning of the entire device are described in detail.

KEYWORDS

rotation universal module, rotary revolving unit, locking pin, security pin, release pin, big bearing flange

1 INTRODUCTION

Currently there are large quantities of handling or robotic devices performing manipulation operations in space. The use of manipulation devices capable of at least five degrees of freedom of movement is recommended in order to achieve efficient manipulation in space. Rotation Universal Module offers the possibility to assemble kinematic chains with the number of degrees of freedom necessary for a particular task [Malega 2007]. The number of degrees of freedom depends on the number of modules mutually interconnected in a kinematic chain [Svetlik 2014]. The first prototypes of Rotation Universal Module were put to a series of tests that revealed deficiencies which were studied in detail and resolved afterwards. Major deficiencies were found on the URM module locking system. This locking system serves for connection of two modules and creating a movable bond between them. For this reason, it is necessary that the system functions correctly without any failures. This became the main issue to be resolved immediately. Individual deficiencies found on the URM module locking system and the actions for their removal are described in the chapters below.

2 ROTATION UNIVERSAL MODULE

Rotation Universal Module (URM) is a rotation module with unlimited degree of rotary movement. This solution is convenient for machinery and equipment requiring unlimited freedom of rotary movement for their functioning [Svetlik 2010a]. From structural viewpoint and concept, the Rotation Universal Module is based on a modular principle which enables it to assemble various machinery and equipment by using a single module type (Fig. 1). If a particular solution is

unsuitable or if there is a need to assemble another machine, thanks to its modularity, the original solution can be re-assembled and the modules can be also used in further applications [Svetlik 2013]. Designed machinery and equipment can achieve different options of movement and degrees of freedom by using unlimited rotation of two adjacent modules which are mutually interconnected via a movement bond.

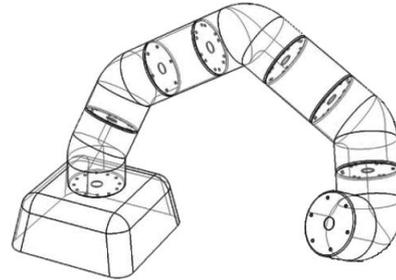


Figure 1. Device assembled of Rotation Universal Modules

Rotation Universal Module has been designed to prevent any components from obstructing unlimited rotation. For this reason, all the components are situated in the body of the module (Fig. 2). As a result, components are protected against external impacts. Each module is equipped with a DC servomotor Faulhaber 3863 012C (204W, 12V, efficiency 85%) which is placed in the centre of the module. The engine is equipped with an incremental Faulhaber IE2-512 sensor able to read 102,400 positions per one revolution. A Faulhaber (38A, 200:1, 20Nm) reducer and an electric brake (6W, 12V, 80Nm) mounted behind the reducer are assembled at the engine's output. For the module to be able to run even after power outage, it is equipped with compensation accumulators LiPol 4in1 (14,8V). The whole module is controlled via a servomotor PID regulation control [Svetlik 2010b]. Nominal output of Rotation Universal Module is 30 rev/min.

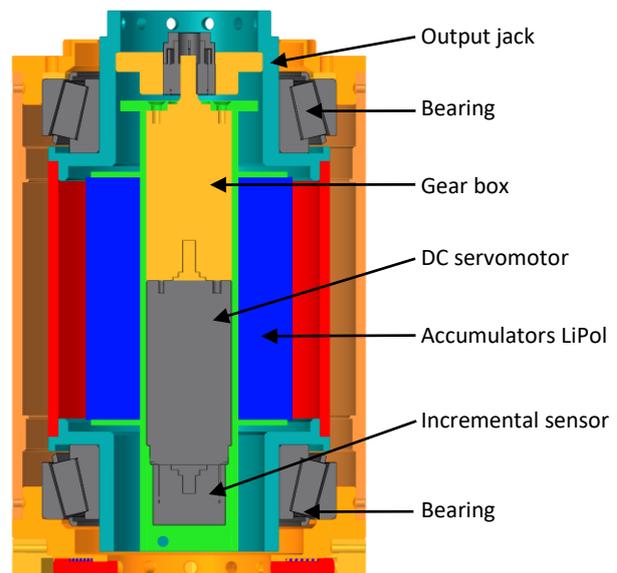


Figure 2. Parts placed in Rotation Universal Module body

The outcome of the above solution is represented by a modular system which enables us to assemble modular robots consisting of identical or type-identical Rotation Universal Modules with unlimited rotary movement. Machinery and equipment assembled from such modules should provide for the best

possible working range and reach the required place in the working area [Svetlik 2012a].

3 ROTATION UNIVERSAL MODULE LOCKING SYSTEM

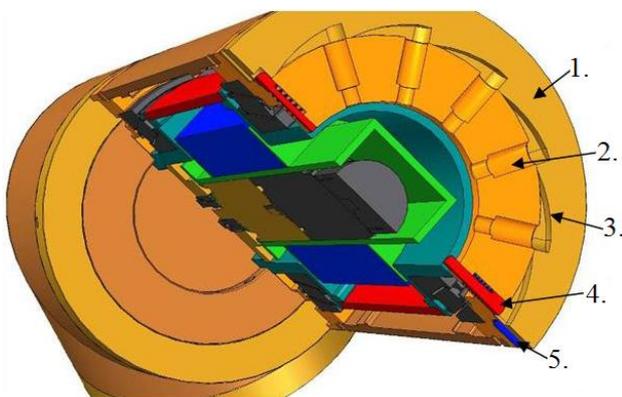
For the purpose of connecting two adjacent modules, it was necessary to design a locking system which would comply with all the requirements. Some of them included high speed and reliability of locking system. The purpose was to achieve time efficiency of connecting the modules not while not compromising the safety of the process. Further requirements for the locking system:

- Light weight,
- Short construction height clearance,
- Robustness,
- Long life,
- Modular structure,
- Easy maintenance,
- Compatibility with industrial robots (flanges),
- Compatibility with a feeder.

The first design of locking system was based on the use of commercial industrial solutions. Upon analysing those products which would comply with the above requirements we arrived at several alternatives. The major ones include TOOL MASTER 500, TYPE 91489, GYMATIC QC 50-A, FESTO CWS SYSTEM. These products do not fully comply with the above requirements for locking system. Their deficiencies include excessive robustness and thus excessive weight or the fact that additional power would be necessary for their functioning, which is undesirable. The final solution was a custom-made design of locking system tailored specifically for Rotation Universal Module.

4 LOCKING SYSTEM PARTS

The basic part of Rotation Universal Module locking system consists of twelve locking pins placed in milled grooves situated around the circumference of the big bearing flange. The rotary revolving unit enables the movement of locking pins. The movement is enabled by grooves milled on the inner side of rotary revolving unit. In order to provide for smooth reverse movement of locking pins, each locking pin has a spring placed in a casing. Securing and adjusting the rotary revolving unit firmness is ensured by four spring-loaded ball pins. These pins are placed around the external circumference of the rotary revolving unit.

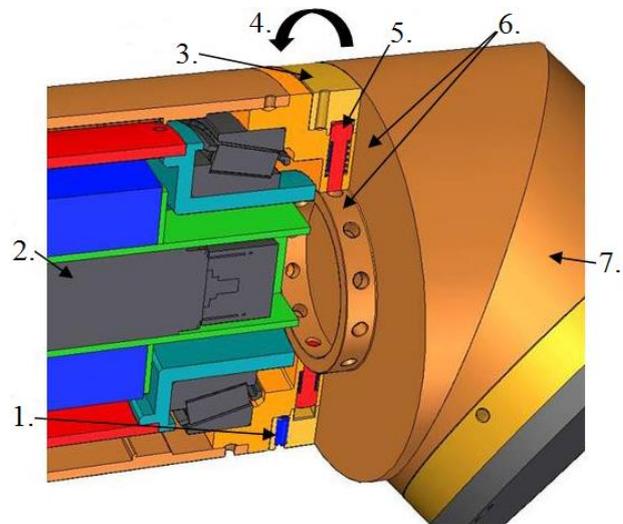


1. Rotary revolving unit 2. Groove for translation movement of locking pin 3. Groove pressing locking pin 4. Locking pin 5. Spring-loaded ball pin

Figure 3. Cross-section of locking system

5 LOCKING SYSTEM FUNCTIONING PRINCIPLE

Rotation Universal Modules are mutually interconnected with each other in the process of machinery and equipment installation. Their mutual interconnection ensures they are locked and a tight connection between two adjacent parts is achieved. After connecting two parts, the rotary revolving unit is slightly turned clockwise. This movement causes the sliding out of locking pins which click into the openings situated on the opposite part. The sliding out of locking pins is enabled by milled grooves placed on the internal circumference of rotary revolving unit. On the external circumference of rotary revolving unit there are four spring-loaded ball pins which during the slight turning of rotary revolving unit click into the openings, in order to prevent the rotary revolving unit from self-release which would cause the disconnection of parts. The sliding out of locking pins and the clicking of spring-loaded ball pins into the openings tightly locks two adjacent models. Anti-clockwise movement of rotary revolving unit pushes locking pins inside which causes disconnection of two parts.



1. Spring-loaded ball pin 2. Piece 1 – active URM module, 3. Rotary revolving unit 4. Rotary release direction 5. Locking pin 6. Exact mounting 7. Piece 2 – passive curvature module 60°

Figure 4. Locking of two Rotation Universal Modules

6 DETECTED DEFICIENCIES OF THE LOCKING SYSTEM

The first three manufactured prototypes of Rotation Universal Module were put through a series of tests, which detected deficiencies. The deficiencies did not prove critical at the designing stage, however, manipulation with Rotation Universal Module clearly showed that they would need to be removed [Korba 2014]. The first problem was found on the rotary revolving unit. During the locking of two adjacent modules in course of which the rotary revolving unit must be slightly turned clockwise, the human hand was gliding over rotary revolving unit surface which made the problems with its turning even worse [Stofa 2016]. This operation is also complicated by the weight of a module itself and by the external smooth surface of rotary revolving unit (Figure 5). The problem can be critical especially in the case of installation, if the personnel were unable to take sufficient hold of rotary revolving unit. The second problem occurred during the movement of assembled kinematic structures. After a certain period of time, partial release of rotary revolving unit occurred, which was undesirable as it could cause disconnection of two modules and thus destruction of the device [Svetlik 2012b]. As follows from the above, the fact is that the spring-loaded ball

pins are not sufficient for securing the rotary revolving unit against self-release. The last problem is also related to mutual interconnectedness of modules. A module weighs up to 5kg, in certain cases it is difficult to achieve the final position during installation in which the pins would after sliding out click into the openings in the opposite module. Therefore, this problem had to be resolved as well to ensure the required functionality of the equipment.

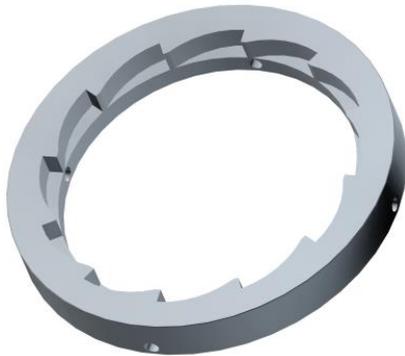


Figure 5. Rotary revolving unit

7 ROTARY REVOLVING UNIT MODIFICATION

The external shape of the rotary revolving unit was modified in order to prevent human hands from gliding over it during the act of locking modules. The first solution was rubber coating the external surface of rotary revolving unit. Rubber coat on the external surface caused an increased diameter of rotary revolving unit which was undesirable. Another solution was milling a series of grooves (Fig. 6) which would enable better hold of rotary revolving unit, thus making locking easier. This would not cause any increase in rotary revolving unit diameter.

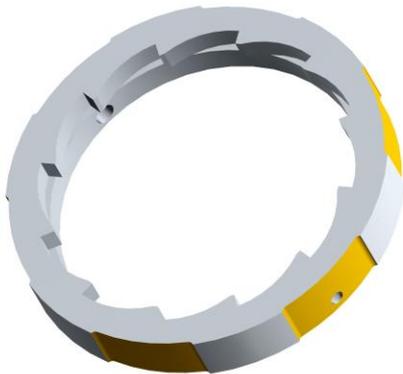


Figure 6. Modified rotary revolving unit

A partial release of rotary revolving unit during the movement of assembled kinematic structures was a more serious problem which required a detailed focus. Four spring-loaded ball pins firmness adjustment and prevention of the rotary revolving unit from reverse self-activated movement had to be replaced. They were replaced by a set of pins which enabled reverse movement of rotary revolving unit only after the pushing of release pins (Fig. 7). The main parts in this solution are two pins which are placed opposite each other. The release pin is placed in the groove present in the rotary revolving unit. The security pin is placed in the groove milled in the big bearing flange. Both pins have springs of different firmness placed in the casing that provides for their reverse movement. The release pin has a softer spring placed in the casing than the security pin.

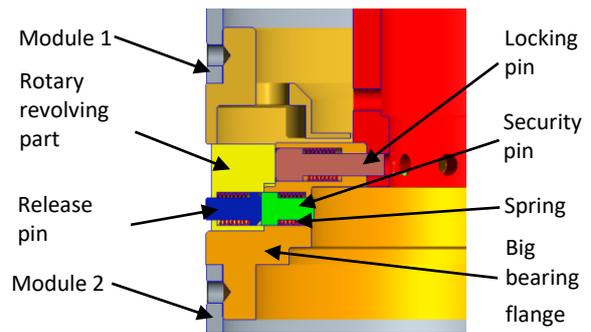


Figure 7. Position of set of pins

When the rotary revolving unit is slightly turned clockwise and locking pins slide out, the security pin clicks into the opening in which the release pin is placed (Fig. 8). As the security pin has a firmer spring in the casing, it pushes the release pin inside the casing, whereas the end of the release pin slides out of the rotary revolving unit.

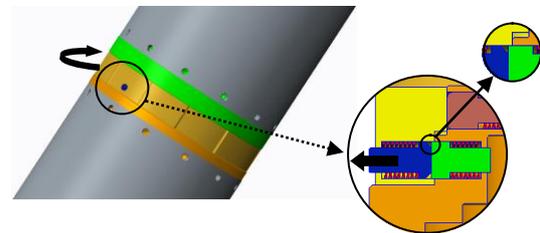


Figure 8. Operation of locking two modules

Pushing the release pin will push the security pin into the casing, which enables slightly turning rotary revolving unit anti-clockwise and unlocking modules (Fig. 9). An identical set of pins is placed opposite the first set. For reverse movement of rotary revolving unit anti-clockwise it is necessary to push the release pins in both places simultaneously. If the pin is pushed only in one place it is not possible to slightly turn the rotary revolving unit and subsequently disconnect the modules.

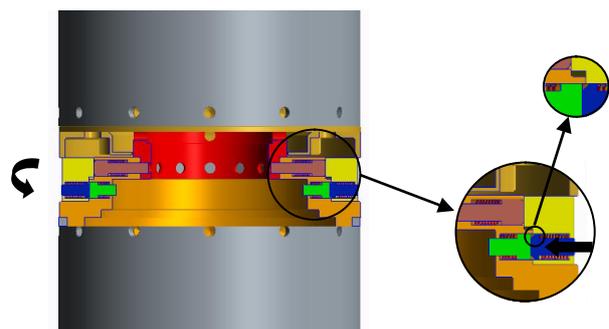


Figure 9. Operation of unlocking two modules

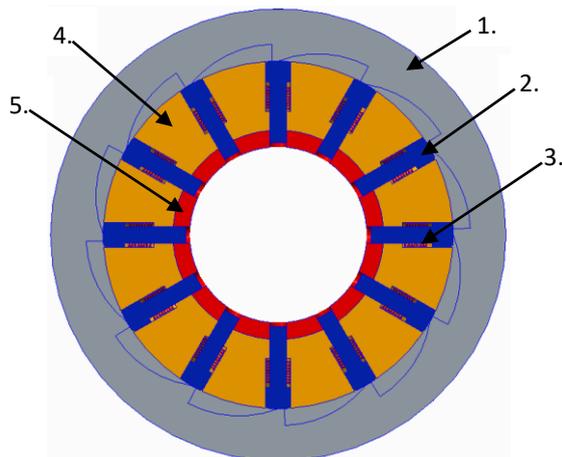
To be able to perform these changes of Rotation Universal Module locking system, certain parts had to be modified. Modification of certain parts was necessary, otherwise it would not be possible to put the suggested modification of locking system into operation. The biggest modification was related to the rotary revolving unit to which two modifications were done simultaneously. To make the placement of two release pins into the rotary revolving unit body possible, it was necessary to increase the height clearance of the rotary revolving unit from the original 12.8 mm (Fig. 5) to 15.8mm (Fig. 6). The thickness of rotary revolving unit has increased by 3mm. This

modification has enabled us to mill casings for the placement of release pins and related springs into the rotary revolving unit body. For the mechanism to be able to function correctly, it was necessary to modify the big bearing flange as well. Similarly to the rotary revolving unit, it was necessary to increase the height clearance from the original 29mm to 32mm. As in the first case, the height increased by 3mm. Then the casings for the placing of security pins with related springs were milled into this part.

When elaborating this solution, an option which would not require any increase in height clearance of the rotary revolving unit and of big bearing flange was also considered. The functioning principle would be identical as in the applied solution but the modification would be in the place of milling casings for placement of particular pins. It was suggested that two locking pins are removed and instead of them casings for release and security pins are milled. The advantage of this solution was that the height of the locking system mechanism would not increase on the whole but it would be at the expense of weakening the locking of adjacent modules. This was highly undesirable because the safety of the whole equipment as such would be disturbed, which was inadmissible. For these reasons this solution was abandoned.

8 LOCKING SYSTEM SHAPE MODIFICATION

The whole Rotation Universal Module locking system has been designed as cylinder-shaped (Fig. 10). This shape complicates the locking of two adjacent parts, especially in case of assembling more complicated devices. The weight of a module is also a con. The major problem occurs at the moment of achieving final position when the rotary revolving unit is slightly turned and locking pins are slid out and clicked into the openings on the opposite part the result of which is the locking of two adjacent parts. During slight rotation of rotary revolving unit the adjacent module slightly turns as well which disturbs the final position for correct interconnecting of two modules. This operation is very difficult for a single worker.



1. Rotary revolving unit, 2. Locking pin, 3. Spring, 4. Big bearing flange, 5. Output jack

Figure 10. Cross-section of original operation system

In order to resolve this problem, certain parts of Rotation Universal Module locking system were modified, namely the big bearing flange and output jack. As displayed in (Fig. 11), both parts are cylinder-shaped in the place of interconnection, which causes the above mentioned gliding of modules and difficult achieving of the final position when locking the two modules. It was necessary to suggest modification that would

enable the achievement of this position in each of respective twelve positions.

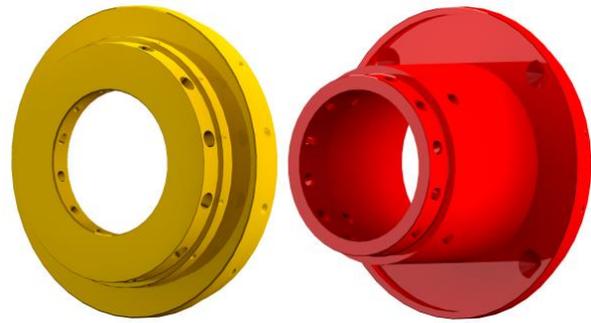


Figure 11. Big bearing flange, output jack

We have modified the shape of parts from the original cylinder-shaped to star-shaped to comply with the above request. Although this modification is more difficult to produce, it will make the assembly of and manipulation with the modules much easier. As follows from (Fig. 12) it was necessary to mill triangle-shaped openings into the big bearing flange to achieve the cog-wheeled shape. The same shape was applied to output jack. This modification led to another modification of the same star-shape as with the two previous parts. This modification was necessary for assembling the module as a whole. This modification is of no mechanical nature, however, it would not be possible to finalise the module without it.

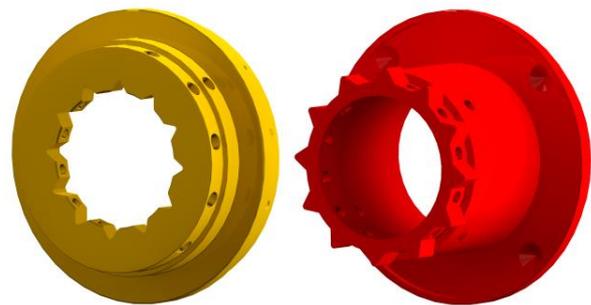


Figure 12. Big bearing flange, output jack after modification

Thanks to the modification of parts, we were able to achieve the required final modifications. During assembly of machinery and equipment there is no gliding of modules when locking them thanks to the star-shaped locking system of Rotation Universal Module (Fig. 13). The final position can be achieved in all twelve positions.

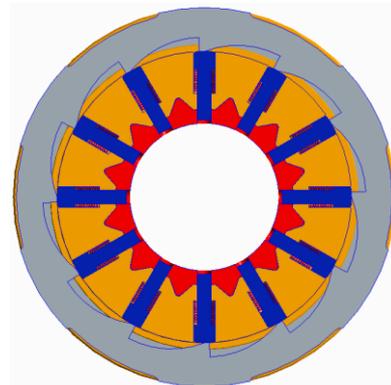


Figure 13. Cross-section of locking system after modification

9 CONCLUSIONS

Rotation Universal Module is a rotary module with unlimited rotation. Its main utilization lies in the assembly of modular robotic systems with various degrees of freedom. Manufacture of the first URM module prototype has enabled performance of a series of tests, which detected certain deficiencies. The deficiencies could not have been specified at the designing stage. Based on the information acquired from testing, all the necessary modifications were done. Modifications were mostly necessary on the URM locking module. This locking system is the main part of connecting two modules and overall assembly of modular systems. The testing has revealed that the movement of assembled modular system causes self-release of the locking system after a certain period of time. This is highly undesirable as it can cause damage to the device. The locking system was therefore modified. The individual modifications have been described above. Modifications were done to rotary revolving unit, big bearing flange, output jack and the whole system was supplemented by two safety pins which prevent self-activated release of locking system. All the modifications were performed in order to achieve required functionality and safety of the device. The modifications described above currently have not been applied to the device as of now due to pending manufacturing of new modified components. After manufacturing and assembly of locking system, the device will be again put to a series of tests. Results thus acquired will be processed and compared to current values. Upon their evaluation, we will obtain the answer whether the modifications have brought required results. With a pro-active approach and performance of series of tests, any potential deficiencies of Rotation Universal Module will be removed in the future and the module will be eventually tuned into required final condition, so that it can be afterwards gradually modified and fine-tuned into a satisfactory construction solution [Dobransky 2016].

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