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# PROBLEMS OF THE COMPENSATION OF CENTRIFUGAL FORCE IN LATHE CHUCKS



**Key words:** lathe chuck, turning, centrifugal force, AM, RP.

**Abstract:** Modern machining technology facilitates mechanical machining at high spindle speeds, which determines the use of machining lathe chucks that guarantee the correct clamping force of the workpiece. The work discusses the problems associated with the compensation of negative effects of centrifugal force acting on the jaws of lathe chucks. Calculations and constructional solutions including the author's own patent application and a description of a model made using additive technology are presented.

**Problemy kompensacji siły odśrodkowej w uchwytach tokarskich**

**Słowa kluczowe:** uchwyt tokarski, siła odśrodkowa, toczenie, AM, RP.

**Streszczenie:** Współczesne maszyny technologiczne umożliwiają obróbkę mechaniczną przy dużych prędkościach obrotowych wrzecion, co determinuje stosowanie uchwytów obróbkowych gwarantujących odpowiednią siłę zacisku przedmiotu obrabianego. W pracy omówiono problematykę związaną z kompensacją negatywnych skutków siły odśrodkowej działającej na szczęki uchwytów tokarskich. Przedstawiono obliczenia i rozwiązania konstrukcyjne, w tym własne objęte ochroną patentową oraz opis modelu wykonanego przy pomocy technologii przyrostowej.

## Introduction

Modern technological machines, especially CNC machine tools, are designed in such a way as to increase the technological parameters, including the spindle speed. In the case of lathes, the increase in rotational speed also causes an increase in the centrifugal force acting on the jaws of the lathe chucks, causing a reduction in the clamping force of the workpiece being clamped. This means that the actual clamping force of the jaws is smaller than originally assumed. This negative effect of the centrifugal force makes it difficult or even impossible to process at high rotational speeds. This situation is described in the article [1]. The lathe design facilitated machining at 4500 rpm, but the three-jaw chucks were limited to 3000 rpm. At higher speeds, the centrifugal force causes the jaws to be unable to clamp the workpiece. Even at speeds of 3000 rpm, there was a situation where the workpiece changed its position in the lathe chuck. This situation caused a serious problem in production.

Nowadays, lathe chucks are produced that are adapted to higher rotational speeds, but it is still a large technical problem described in various works, e.g., [2–4].

This work describes various construction solutions, including the author's own patent application [5]. The basic calculations of the value of the acting centrifugal force and the model of the chuck manufactured using rapid prototyping technology are presented.

## 1. Solutions for turning lathe chucks with centrifugal force compensation

Typically, in order to compensate for the effects of centrifugal force in turning lathes, solutions based on the following:

– The use of counterweights;
– Increasing the clamping force; and,
– Using lighter materials for the jaws, e.g., aluminium.

Here are some examples of patent solutions. For example, patent PL102905B2 [6] described a self-centring three-jaw chuck with mechanical fastening and with compensation of the clamping force. In this chuck, the compensation of the centrifugal force takes place by placing the counterweights on two-armed levers whose axes are placed parallel to the handle axis.

Lathe chucks consists of a body, a scroll plate, which is located in the hole of the body, and the pulling sleeve meshed with skewed T-slots with three jaws. In the body, there are levers mounted on the bolts. Each of the short arms of the lever rests on the base jaw, while on the long arms of the lever, counterweights are mounted.

The lathe chuck works similarly to lathe chuck with a wedge sleeve. The actuator placed on the other end of the spindle by means of special dies or an elongated piston rod axially moves the sleeves, and this causes the radial movement of the jaws by fastening or unmounting the workpiece. The compensation of the drop in the clamping forces during rotation is accomplished by using counterweights that are attached to the long arms of the lever.

Centrifugal forces acting on the counterweights are transferred by the levers to the jaws and balance the centrifugal forces acting on the jaws of the handle. Balancing the centrifugal forces acting on the jaws can be partial, full, or even increasing the clamping force at increasing rotational speeds. It depends on the specific design of the chuck and more precisely on the weight of the counterweights and the leverage. The disadvantage is the slightly restricted range of movement of the jaws. An unfavourable feature of this solution is the fact that, depending on the diameter of the fixed object, the inclination of the arms of the double-sided lever changes, which affects the value of compensating the centrifugal force.

Another interesting solution is the Polish patent 127888 [7]. Compensation of the centrifugal force at high rotational speeds takes place via a lever system with counterweights. On both sides of the master jaws, levers are eccentrically mounted on the pins, which are contacted with shorter ends with side planes of the jaws. Longer ends are coupled with weights. Under the influence of high rotational speed, the movement of the weights from the centre of the lathe chucks is induced by centrifugal force, which causes pressure on the longer ends of the lever, their rotation about the axis of the pins, and eccentric tightening of the lateral planes of the master jaws. This shape allows compensation of the drop in clamping forces of the jaws of the chuck.

An unquestionable advantage of the mentioned solution is its simple construction. However, due to the fact that there are friction elements here, the effectiveness of the handle depends on the quality of workmanship and operating conditions. For example, coolant or lubricant may enter the contact zone of the lever and jaws, which is highly probable under the machining conditions, and then the friction force will be reduced opposite to the centrifugal force acting on the jaw. Moreover, the friction forces can be different in individual contacts, and it can cause uneven clamping of the workpiece.

## 2. Proposal to solve the problem

In order to compensate for the effects of centrifugal force acting on the jaws of the lathe chuck, the authors propose counterweights that act on the jaws of the chuck during rotary motion through gears. This solution is covered by patent application [5], and it is described in this paper and is shown in Fig. 1.

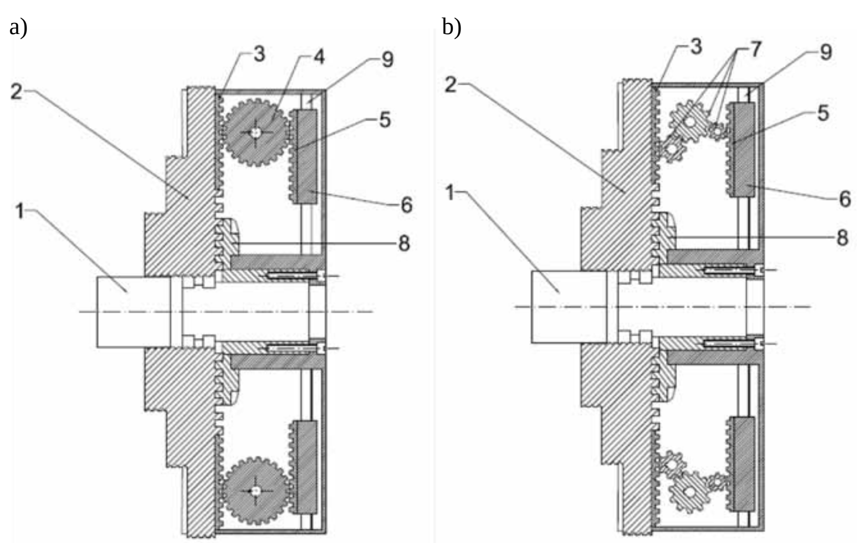


**Fig. 1. Lathe chuck with centrifugal compensation, a) with one gearwheel, b) with gearwheels (own development [5]): 1 – workpiece, 2 – jaw, 3, 5 – gear rack, 4 – gearwheel, 6 – counterweight, 7 – gear, 8 – scroll plate, 9 – guideways**

The lathe chuck shown in Fig. 1a has two clamping jaws for clamping the workpiece 1, wherein the clamping jaw 2 and the counterweight 6 have gear racks 3 and 5 between which a gear 4 is mounted. The turning chuck, according to Fig. 1b, has two jaws 2 clamping the work piece 1, wherein the clamping jaw 2 and the counterweight 6 have gear racks 3 and 5 between which a gearing 7 is installed.

The principle of working of the handle is analogous to the conventional solutions of the scroll plate chucks. The rotation of the scroll plate 8 causes the jaws to move in the radial direction to mount or unmounts the workpiece 1. The compensation of the effects of centrifugal force is effected by the sliding counterweights 6 supported on the guideways 9. When the lathe chuck rotates about its axis, the centrifugal force acts on the counterweight and it is transmitted by the gear rack 3 and 5 and gear 4 (or gears 7) for the jaws 2 of the lathe chuck and balance the centrifugal forces acting on the jaws of the handle. The gearing 7 allows one to increase the value of the force coming from the centrifugal force acting on the jaws by selecting the appropriate ratio.

The beneficial effect of the presented construction solution is full compensation of the centrifugal force with the possibility of increasing the clamping force. The increase in the jaw clamping force is achieved by using a gearing that increases the value of the force coming from the centrifugal force. The construction solution presented above can be used in all varieties of lathe chucks.

## 3. Calculation of the value of centrifugal force

Centrifugal force is the inertia force found in rotating reference systems that belong to non-inertial systems. The centrifugal force is not caused by a specific interaction, but results from the movement of the reference system itself. If the reference system moves with respect to the inertial system at the velocity *v* in the circle with radius *r*, then the centrifugal force described will act on all parts in this system. The value of the centrifugal force is proportional to the mass of the moving body, the radius of curvature on which the body moves, and the square of the rotational speed. The forces acting on the jaw during the rotation of the chuck is shown in Fig. 4.

The real value of the force acting on the jaw is

$$F_{zr} = F_z - F_c + F_{pc} \tag{1}$$

where

$F_{zr}$ – actual clamping force (when the lathe chuck is rotating),
$F_z$ – jaw clamping force (when the lathe chuck is not rotating),
$F_c$ – centrifugal force acting on the jaw,
$F_{pc}$ – centrifugal force acting on a counterweight.

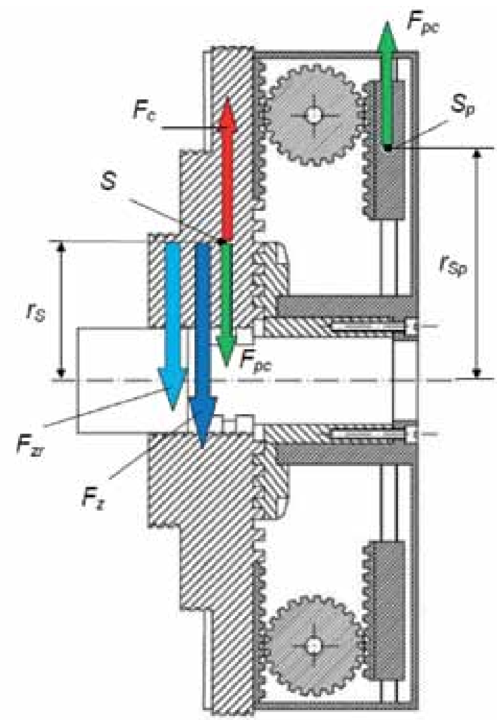


**Fig. 2. Forces acting on the jaw during rotation of the lathe chuck (own elaboration): S – the jaw centre of gravity, $S_p$ – the counterweight centre of gravity, $r_S$ – distance between the jaw centre of gravity and the lathe chuck axis, $r_{Sp}$ – distance between the counterweight centre of gravity and the lathe chuck axis, $F_c$ – centrifugal force acting on the jaw, $F_{pc}$ – centrifugal force acting on the counterweight, $F_z$ – the jaw clamping force (when the lathe chuck does not rotate), $F_{zr}$ – the real clamping force (when the lathe chuck rotate)**

The value of the clamping force is given manually or mechanically depending on the design of the lathe chuck. The values of centrifugal forces are calculated from technical formulas containing unit conversions, as in the following:

$$F_c = \frac{\pi^2}{900} \cdot m_s r_s n^2 \tag{2}$$

where

$F_c$ [N] – centrifugal force acting on the jaw,
$m_s$ [kg] – mass of the jaw,
$r_s$ [m] – distance between the centre of gravity of the jaw and the axis of the chuck,
$n$ [obr/min] – spindle speed,

$$F_{pc} = \frac{\pi^2}{900} \cdot m_p r_{sp} n^2 \tag{3}$$

where

$F_{pc}$ [N] – centrifugal force acting on a counterweight,
$m_p$ [kg] – weight of the counterweight,
$r_{sp}$ [m] – distance between the centre of gravity of the counterweight and the axis of the lathe chuck.

If we calculate the centrifugal force value for the sample data: jaw mass $m_s$ = 1 kg, distance between the centre of gravity of the jaw and the chuck axis $r_s$ = 0.08 m, spindle speed $n$ = *3000* rpm, its value will be $F_c$ = 2513 N. You can see then that this value is not small and seriously hinders machining at higher spindle speeds. This can be seen in the diagrams shown in Figs. 3 and 4.

Figure 3 shows the decrease in the actual value of the clamping force at the jaw, the values of which were calculated from formulas (1) and (2). The value of clamping force $F_z$ = 30 kN was assumed. The calculations were made without compensation for the centrifugal force ($F_{pc}$ = 0) for the following data:

$F_{zr1}$ for $r_s$ = 0.08 mm, $m_s$ = 1 kg,
$F_{zr2}$ for $r_s$ = 0.08 mm, $m_s$ = 2 kg,
$F_{zr3}$ for $r_s$ = 0.08 mm, $m_s$ = 3 kg
$F_{zr4}$ for $r_s$ = 0.10 mm, $m_s$ = 1 kg,
$F_{zr5}$ for $r_s$ = 0.12 mm, $m_s$ = 1 kg.

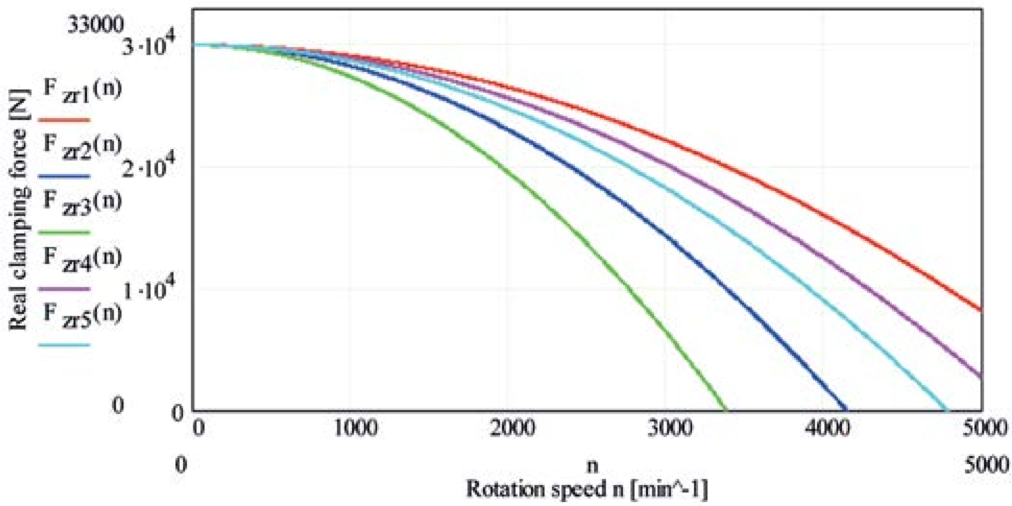


**Fig. 3. Real clamp force of jaw without compensation of centrifugal force**

The above data contains ranges of values typical for lathe chucks. From the graphs shown in Fig. 3, it can be clearly seen that, above the rotational speed spindle of 3,000 rpm, there is a significant decrease in the value of the clamping force on the jaws. Therefore, when machining, especially with the use of CNC machine tools, it is necessary to use lathe chucks with centrifugal force compensation or clamps with increased clamping force, with the latter usually being used.

Figure 4 shows the change in clamping force values for the same parameters as in Fig. 3, but taking into account the centrifugal force acting on the counterweight, i.e. taking into account partial compensation.

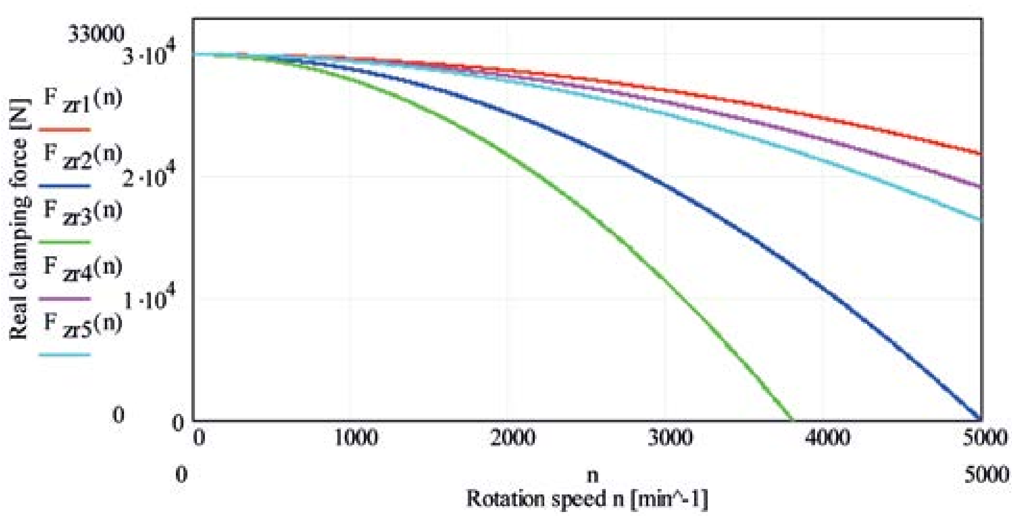


**Fig. 4. Real clamp force of jaw with partial compensation of centrifugal force**

Figure 4 shows the actual value of the clamping force on the jaw with partial compensation of the centrifugal force for the following counterweight data:

$m_p$ = 0.5 kg for all clamping forces,

$r_{sp}$ = 0.10 m for $F_{zr1}$, $F_{zr2}$, $F_{zr3}$,

$r_{sp}$ = 0.08 m for $F_{zr4}$,

$r_{sp}$ = 0.06 m for $F_{zr5}$.

From the graphs shown in Fig. 4, it can be clearly seen that even the use of partial centrifugal compensation, when the weight of the counterweight is half the weight of the jaw, gives a definite improvement in the applicability of the lathe chuck.

If we increase the weight of the counterweight by taking, for example, $m_p$ = 1 kg, i.e. as much as the weight of the jaw in the three cases analysed, then we should receive full compensation of the centrifugal force acting on the jaw. This case is shown in Fig. 5.

Graphs shown in Fig. 5 were made for data similar to the aforementioned example, Fig 4. The difference is in the counterweight mass $m_p$ = 1 kg. Curve $F_{zr4}$ illustrates full compensation of centrifugal force, because the jaws and counterweights have the same mass equal 1 kg and the distance between the mass and axis of rotation are the same $r_S = r_{Sp}$ = 0.08. Curve $F_{zr1}$ illustrates the increase in clamping force, because the distance between the counterweight and the rotation axis is smaller than between the jaws and rotation axis.

All the graphs presented above illustrate the large possibilities of not only compensating the centrifugal force in the lathe chuck but also increasing the clamping force in the event of an increase in the rotational speed of the chuck.

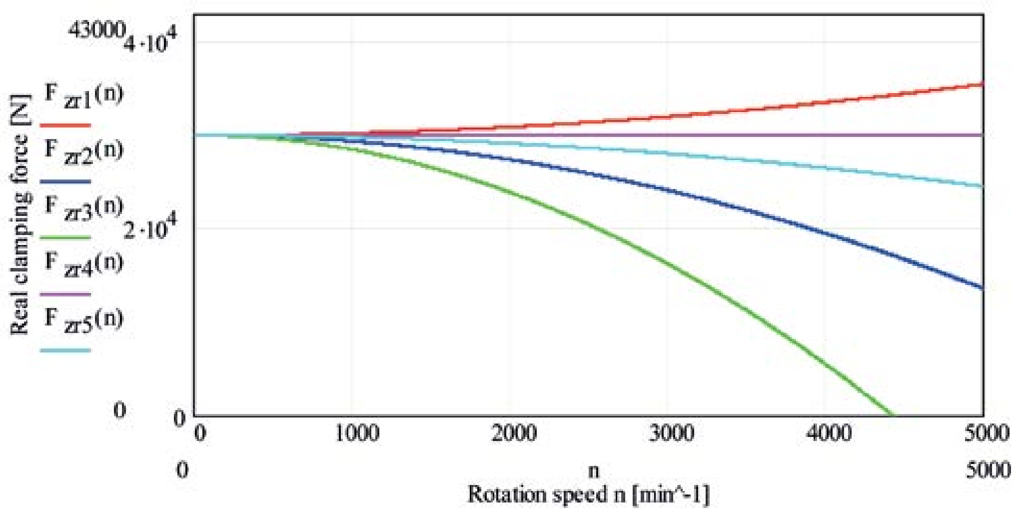


**Fig. 5. Real clamp force of jaw with compensation of centrifugal force**

## 4. Lathe chuck model prepared by Selective Laser Sintering technology

One of the commonly use rapid prototyping technology, Selective Laser Sintering – SLS, was used to manufacture the model. The authors of this work have often used additive technologies to produce components of machining chucks or clamping components, which was very helpful during this production. Some of the solutions are patents [8–12].

The chuck model [5] was made using a CAD program, as shown in Fig. 6.

3D CAD model does not allow organoleptic evaluation of the functionality of the designed handle. Therefore, before creating (making) the prototype version intended for real functional tests, it was decided to implement the model using rapid prototyping technology. The cost aspect was also considered, i.e. the cost of the model made with additive technology is much smaller than the actual prototype. It reduced the cost of changes in the final prototype. This method of operation has already been successfully used in several other cases of prototype design using rapid prototyping technology.

The lathe chuck elements manufactured by SLS technology (material – polyamide powder PA 2200) and the Formiga P100 machine are shown in Fig. 7, and the assembled chuck is shown in Fig. 8.

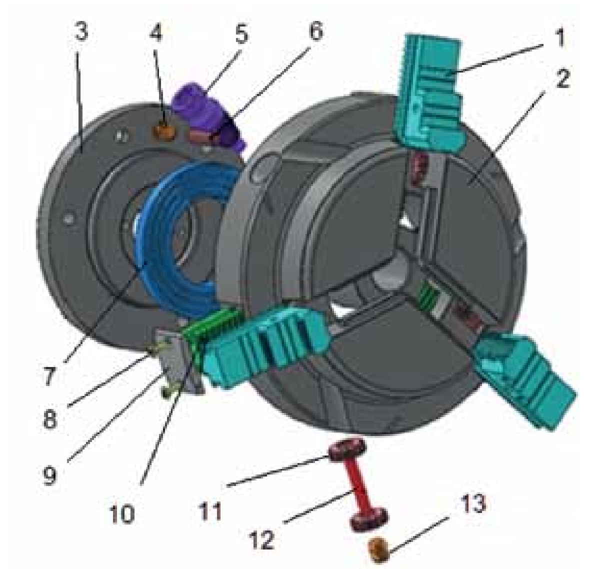


**Fig. 6. Lathe Chuck – 3D CAD Model. [13]. 1 – jaw, 2 – chuck body, 3 – chuck back, 4 – pin locking screw, 5 – pinion, 6 – pin, 7 – scroll plate, 8 – fastening screw, 9 – cover counterweight, 10 – counterweight, 11 – gear, 12 – shaft of gear, 13 – shaft screw**

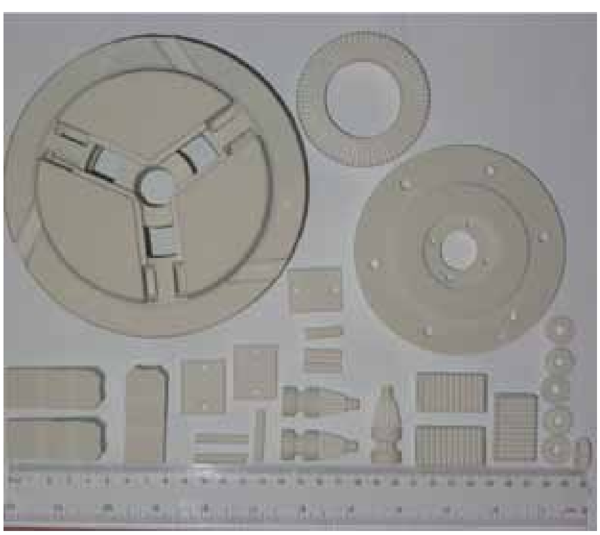

**Fig. 7. Elements of prototype**

**Fig. 8. Model of the assembly lathe chuck**

The prepared chuck allowed the evaluation of the functionality of the whole complex model. Some conclusions have been drawn regarding the further modernization of the lathe chuck to ensure compensation of the effects of centrifugal force.

## Conclusion

Based on the current state of the art and also analysing a prepared prototype of a lathe chuck model, there appears to be a solution for compensation of the centrifugal force with the use of counterweights and gears. We can conclude that it may have an important role in the further development of the designed lathe chuck. After the evaluation of the model, the need for a certain modifications of the construction to reduce the overall dimensions of the prototype was found. Therefore, work was undertaken to build a real fully functional prototype as part of the Incubator of Innovation project granted by the Ministry of Education in Poland.

The simulation of the effect of centrifugal force on the clamping force as a function of the rotational speed spindle shown in Figs. 3, 4, and 5 shows different possibilities of achieving compensation, (incomplete, full, and positive), which can increase the clamping force as the spindle speed increases.

## Acknowledgements

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