

CENTRIFUGAL FORCE COMPENSATION IN MACHINING LATHE CHUCKS – PATENTS STATE OF ART

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Modern technological machines, especially CNC machine tools, are designed to enable increased technological parameters, including spindle speed. In the case of lathes, increasing rotational speed also increases the centrifugal force acting on the jaws of the lathe chucks, reducing the clamping force on the workpiece being held. This means that the actual clamping force of the jaws is lower than originally expected. This negative effect of centrifugal force makes machining at high rotational speeds difficult or even impossible. This article, based on several patent descriptions, presents various chuck designs that compensate for the negative effects of centrifugal force.

KEYWORDS

Lathe chucks, centrifugal force, patents

1 INTRODUCTION

A case of the negative impact of centrifugal force on a machining process was described in [Mark 2004]. The lathe was designed to operate at 4500 rpm, but three-jaw chucks were limited to 3000 rpm. At higher speeds, centrifugal force caused the jaws to open and lose contact with the workpiece. Even at speeds of around 3000 rpm, the part would shift its position in the chuck. This situation caused serious production disruptions. Such cases are quite common in machining, but they are not widely reported in the literature. Typically, the chuck manufacturer provides information about the rotational speed at which a given chuck is used.

Various design solutions are used to prevent the negative effects of centrifugal force on the jaws of machining chucks. Sometimes, the clamping force acting on the jaws is increased. However, such methods cannot be used for turning soft materials or thin-walled sleeves, as they cause deformation. Counterweights are typically used to compensate for centrifugal force, and various methods are used to transfer the centrifugal force generated by these counterweights to the jaws.

In this paper, several selected patents are described to show different methods of compensating for the centrifugal force occurring during turning.

2 PATENTS

Presented below is a patent analysis selected to be consistent with the centrifugal force compensation concept proposed by the authors. Most patent descriptions concern design solutions using a counterweight that generates a centrifugal force during the rotation of the chuck, which compensates the centrifugal force acting on the chuck jaws by means of an appropriate

mechanical system. Figure 1 shows one of the older patent descriptions [Stós 1979] proving that there was a need to modernize lathe chucks to meet the requirements of high-performance and high-speed machining methods.

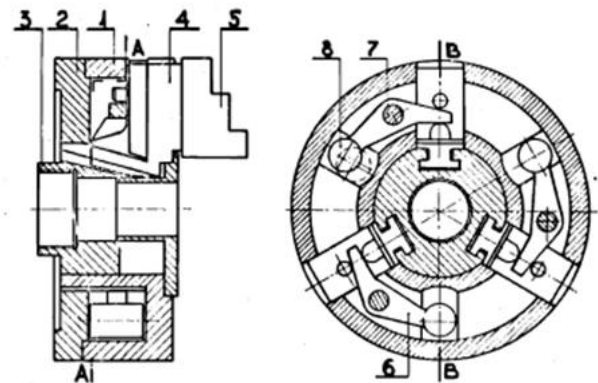


Figure 1. Lathe chuck with centrifugal force compensation. 1 – steel body, 2 – driving plate, 3 – sleeve, 4 – jaws, 5 – upper jaws, 6 – lever, 7 – pin, 8 – counterweight [Stós 1979].

The operating principle of the chuck (Fig. 1) is similar to that of chucks with a wedge-shaped drawing sleeve. The movement of the sleeve 3 is achieved by a servomotor located on the other side of the spindle. The longitudinal movement of the sleeve 3 causes radial movement of the chuck jaws 5. Compensation for the centrifugal force acting on the jaws, and thus the decrease in clamping force, is achieved by counterweights 8 attached to the longer arms of levers 6. The centrifugal force acting on counterweight 8 is transmitted through levers 6 to jaws 4 and compensates for the centrifugal forces acting on these jaws. The axes of the individual levers are parallel to the axis of the chuck, which is characteristic of this patent.

Counterweights were also used in another patented design [Podolej 1985], which is shown in Figure 2.

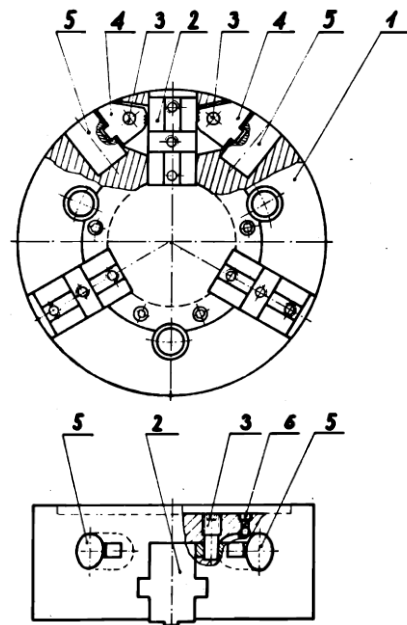


Figure 2. Self-centering lathe chuck with centrifugal force compensation. 1 – chuck body, 2 – base jaws, 3 – pins, 4 – levers, 5 – counterweights, 6 – latches, [Podolej 1985].

In this holder (Fig. 2), the jaws 2 are also engaged with a drawing sleeve. The aim of developing this invention was to provide a more compact design than in designs using lever systems. Therefore, on both sides of the base jaws, levers 4 are mounted eccentrically on pins 3, which are significantly shorter

than the levers used in other designs. The shorter ends of these levers are in contact with the side surfaces of the jaws. Their longer ends are engaged with weights 5. Latches 6 establish the initial position of the weights 5. At high rotational speed, centrifugal force causes the weight 5 to move away from the center of the holder. This causes pressure on the longer ends of the levers 4, their rotation about the axis of the pins 3, and the eccentrically formed shorter ends to clamp the side surfaces of the base jaws 2.

Using a lever system to transfer the centrifugal force of counterweights to the jaws of the chucks has several disadvantages. A disadvantage of this design is that the inclination of the double-sided lever arms changes depending on the diameter of the clamped object, which affects the value of the component compensating the centrifugal force (in the case of the chuck shown in Fig. 1). In the chuck shown in Fig. 2, the effects of centrifugal force are not fully compensated.

To avoid these unfavorable phenomena, a centrifugal force-compensated jaw lathe chuck was developed for fixing and securing workpieces during machining. It is equipped with counterweights. The chuck jaws and counterweights are equipped with toothed racks, between which at least one gear is installed. There may be more than one gear, but their number is odd [Bochnia 2018]. The chuck's design is shown in Figure 3.

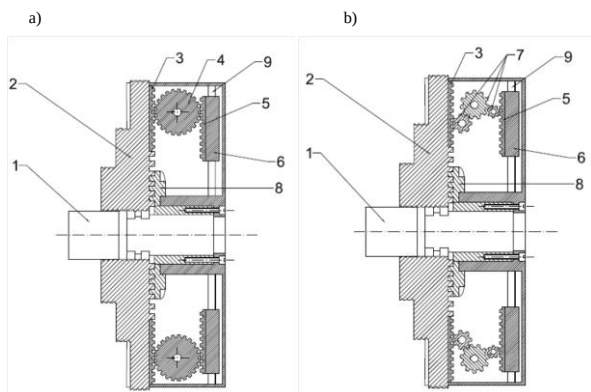


Figure 3. Lathe chuck with compensation of the effects of centrifugal force, a) with single-stage gear, b) with two-stage gear. 1 – workpiece, 2 – jaw, 3, 5 – toothed rack, 4 – gear, 6 – counterweight, 7 – toothed rack, 8 – spiral disc, 9 – rack [Bochnia 2018].

In the chuck shown in Fig. 3, the gear axes are perpendicular to the chuck axis, and the planes of symmetry of the jaw toothed bars, the planes of symmetry of the counterweight bars coincide. A beneficial effect of this design solution is full compensation of centrifugal force, with the possibility of increasing the jaw clamping force. The increase in jaw clamping force is achieved by using a gear transmission (more than one gear), which increases the force derived from centrifugal force. The operating principle of the chuck is analogous to conventional chuck designs with a spiral disc. Rotation of the spiral disc 8 causes radial displacement of the jaws to clamp or unclamp the workpiece 1. Compensation for the effects of centrifugal force is achieved by counterweights 6, slidingly mounted on the racks 9. When the chuck rotates around its axis, the centrifugal force transferred by the racks 3 and 5 and the gears 4 (or gears 7) to the jaws 2 of the chuck acts on the counterweights 6, balancing the centrifugal forces acting on the jaws. By selecting the appropriate ratio, the gear 7 allows for increasing the value of the force derived from the centrifugal force acting on the jaws.

A simplified distribution of forces acting on the surface is shown in Figure 4 [Bochnia 2018].

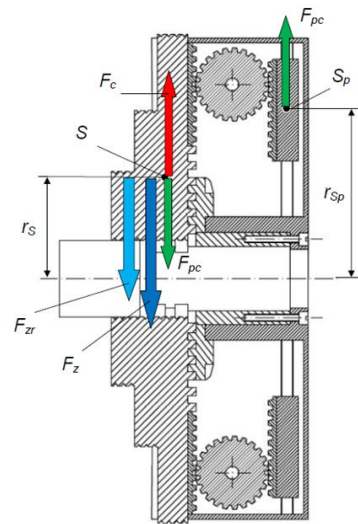


Figure 4. Forces acting on the jaw during rotation of the lathe chuck (own elaboration): S – the jaw centre of gravity, S_p – the counterweight centre of gravity, r_s – distance between the jaw centre of gravity and the lathe chuck axis, r_{sp} – distance between the counterweight centre of gravity and 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) [Bochnia 2018].

Calculations of the centrifugal force value after its compensation, along with simulation for various rotational speeds, are discussed in detail in [Bochnia 2018]. The CAD model of the holder and its prototype made using selective laser sintering (SLS) technology are shown in Figures 5 and 6.

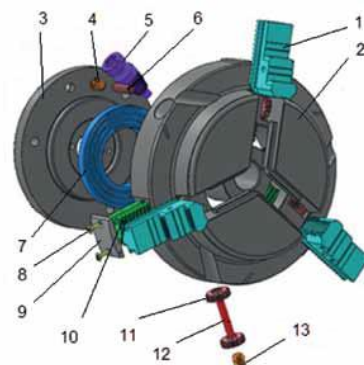


Figure 5. Lathe Chuck – 3D CAD Model. [13]. 1 – jaw, 2 – chuck body, 3 – chuck back, 4 – pin locking screw, 5 – pinion, 6 – pin, 7 – scroll plate, 8 – fastening screw, 9 – cover counterweight, 10 – counterweight, 11 – gear, 12 – shaft of gear, 13 – shaft screw [Bulira 2017].



Figure 6. Model of the assembly lathe chuck produced by additive technology SLS. [Bulira 2017].

The completed model allowed for the assessment of the correctness of the design and its functionality, and also became an inspiration for further work on the compensation of the centrifugal force occurring in lathe chucks.

Figure 7 shows a jaw lathe chuck with compensation for the effects of centrifugal force, equipped with counterweights in the form of hydraulic tanks.

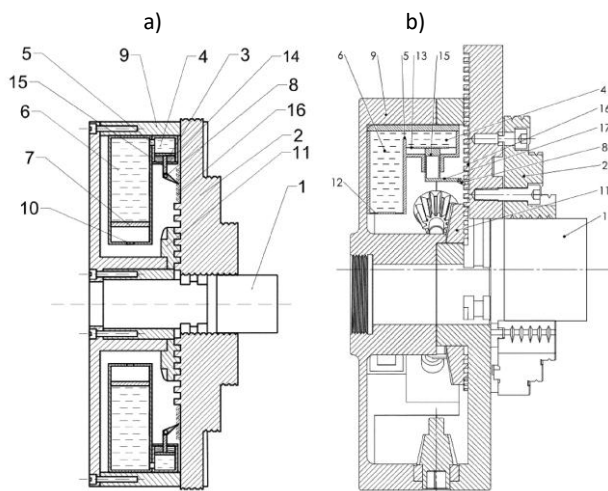


Figure 7. Jaw lathe chuck with compensation of the effects of centrifugal force – hydraulic compensation; a) with a piston hydraulic tank, b) with a membrane hydraulic tank; 1 – workpiece, 2 – chuck jaws, 3 – pistons of passive tanks, 4 – passive tanks, 5 – channels, 6 – active tanks, 7 – pistons of active tanks, 8 – ratchet mechanisms, 9 – housing (body), 10 – vent holes, 11 – spiral disc, 12 – membranes of active tanks, 13 – membranes of passive tanks, 14 – springs, 15 – piston rods, 16 – toothed jaw racks, 17 – piston rod arms [Bochnia 2019].

The operating principle of the chucks (Fig. 7) is analogous to conventional chuck designs with a spiral disc. Rotation of the spiral disc 11 causes the clamping jaws 2 to move radially to clamp or unclamp the workpiece 1. When the chuck rotates around its axis, a centrifugal force from its mass acts on the jaws 2, reducing the clamping force. Compensation for the effects of the centrifugal force of the jaws is achieved by the pressure of the pistons 3 or diaphragms 13, via ratchet mechanisms 8 and piston rods 15, on the jaws 2 in the radial direction. The force acting on the pistons 3 or diaphragms 13 comes from the pressure of the liquids in the passive tanks 4 and active tanks 6, caused by the centrifugal force acting on the masses of these liquids. The masses of liquids in the active tanks 6 are many times greater than the masses of liquids in the passive tanks 4. The pistons 3 and the diaphragms 13 perform a small movement resulting from the limitations of the ratchet mechanisms 8. When the handle does not rotate, and the pistons 3 are not subjected to liquid pressure, the springs 14 move the pistons 3 of the passive tanks 4, and the flowing liquid moves the pistons 7 of the active tanks 6 to their initial position. In the solution shown in Fig. 7b, after switching off the machine tool, the diaphragms 12, 13 of the passive tanks 4 and the active tank 6 equalize the liquid pressure in both tanks. Yet another method of transferring the centrifugal forces caused by counterweights and compensating the centrifugal forces acting on the jaws is used in the lathe wedge chuck shown in Figure 8 [Bochnia 2020].

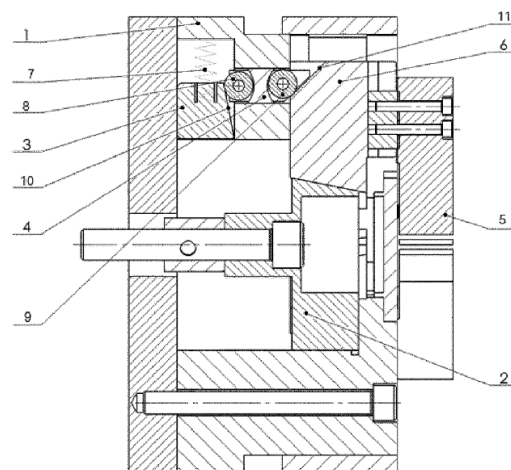


Figure 8. Wedge lathe chuck with compensation of the effects of centrifugal force; 1 – body, 2 – drawing sleeve, 3 – counterweights, 4 – slider, 5 – interchangeable jaws, 6 – base jaws, 7 – springs, 8 and 9 – slider rollers, 10 – wedge surface of the counterweight, 11 – wedge surface of the base jaws, [Bochnia 2020]

The operating principle of the chuck according to the invention is analogous to conventional chuck designs with a wedge-shaped drawing sleeve. Axial displacement of the drawing sleeve 2 causes radial displacement of the jaws to clamp or unclamp the workpiece. Compensation for the effects of centrifugal force is achieved by counterweights 3, slidably mounted in the chuck body 1. When the chuck rotates around its axis, the centrifugal force acts on the counterweights 3. This force is transferred through sliders 4, equipped with rollers 8 and 9 to reduce friction, to the base jaws 6, which are connected to the interchangeable jaws 5, and balances the centrifugal forces acting on the chuck jaws. Springs 7 are positioned between the body 1 and the counterweights 3, which, after the workpiece is unclamped, support the movement of the counterweights 3 towards the chuck axis. The 3D CAD cross-section view of the holder is shown in Figure 9.

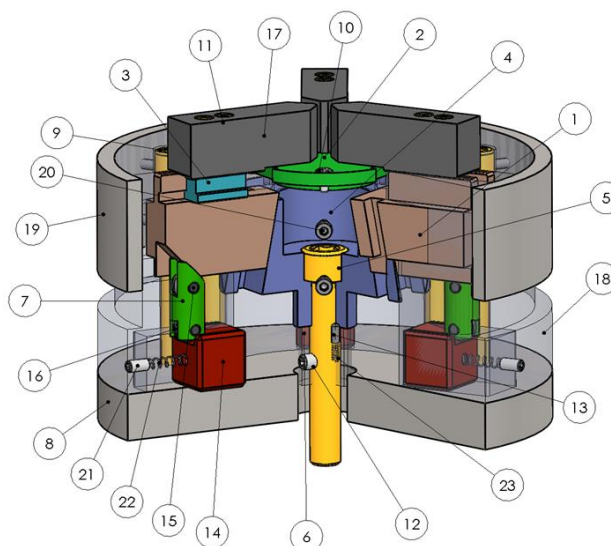


Figure 9. Wedge lathe chuck with compensation of the effects of centrifugal force; 1 – base jaw, 2 – top cover, 3 – stone, 4 – slide, 5 – tie rod screw, 6 – sleeve, 7 – pin, 8 – cover, 9 – mounting screw, 10 – top cover mounting screw, 11 – jaw mounting screw, 12 – locking screw, 13 – pin, 14 – counterweight, 15 – pin, 16 – roller, 17 – replaceable jaw, 18 – body, 19 – clamp, 20 and 21 – mounting screws, 22 and 23 – springs, [Seredyn 2019]

Figure 10 shows a simplified distribution of forces acting on the grip elements.

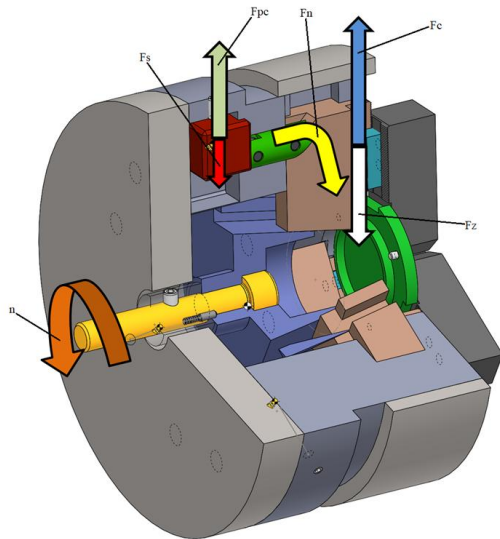


Figure 10. Distribution of forces in the chuck during rotation, n – rotational speed, F_z – jaw clamping force, F_c – centrifugal force acting on the jaw, F_n – force compensating the centrifugal force acting on the jaw, F_{pc} – centrifugal force acting on the counterweight, F_s – spring force acting on the counterweight, [Seredyn 2019].

Typically, the spring force acting on the counterweight is many times smaller than the other forces and can be neglected in the calculations. The angles of inclination of the counterweight's wedge surfaces and the wedge surfaces of the base jaws are of great importance. The values of these angles and the masses of the counterweights determine the values of the compensating force F_n .

To avoid problems related to counterweights, a design using springs made of shape memory materials was proposed, which is shown in Figure 11 [Bochnia 2021].

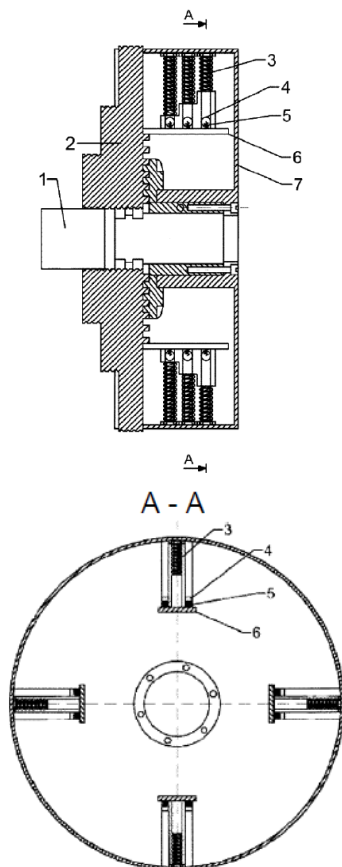


Figure 11. Lathe chuck with compensation of the effects of centrifugal force; 1 – workpiece, 2 – chuck jaws, 3 – springs made of shape memory material, 4 – magnets, 5 – springs, 6 – clamps, [Bochnia 2021].

The operating principle of the chuck (Fig. 11) is analogous to conventional chuck designs with a spiral disc. Rotation of the spiral disc causes the jaws 2 to move radially to clamp or unclamp the workpiece 1. When the chuck rotates around its axis, a centrifugal force from its mass acts on the jaws 2, reducing their clamping force. Compensation for the effects of the centrifugal force is achieved by the pressure of springs 3 through clamps 6 on jaws 2 in the radial direction. The force acting on clamps 6 comes from springs 3 made of a material with magnetic shape memory. Springs 3 are made of an alloy exhibiting a bidirectional magnetic shape memory effect and are shaped so that when a magnetic field is applied, they are in an extended position and additionally act on jaws 2, pressing them down. When the magnetic field is removed, they are in a compressed position, releasing the clamping force. When the rotational speed increases, the centrifugal force acting on magnets 4 increases, which causes it to deflect and move along the springs 3. This initiates the process of elongation of the springs and an increase in the pressure force on the jaws 2 through the clamps 6.

Table 1 below presents a summary of the characteristics of selected mounts, based on the authors' opinions and experience, where : 1 indicates the weakest solution, and 3 the best.

Table 1. Comparison of selected patents

	Mass	Compensation possibility	Additional function - Advanatgeous	complexity
Stós 1979 - Patent 102905	1	1	1	3
Podolej 1985 - Patent 229382	1	1	1	3
Bochnia 2018 - Patent PL 230620	3	3	2	3
Bochnia 2019 - Patent PL 231798	3	3	2	1
Bochnia 2020 - Patent PL 234713	2	2	1	2
Bochnia 2021 - Patent PL 237381	3	3	3	3

As is evident, the evolution of chuck design has led to increased complexity; however, this effect into benefits such as reduced weight and numerous additional features.

3 CONCLUSION

The discussion presented here shows that the problem of centrifugal force acting on the jaws of lathe chucks has been recognized for many years. This problem is one of the obstacles to achieving increased rotational speeds of machine tool spindles.

The possibilities of compensating the centrifugal force are limited because most methods involve the use of counterweights in various design configurations, which involve a significant increase in the mass and dimensions of the handles.

An interesting design is the handle using shape memory materials, which can influence the construction of more universal structures. This solution not only enables independent control but also reduces the amount of rotating mass. Currently, advanced 3D printing allows the production of not only nitinol springs but also entire systems, such as counterweights.

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