MILLING HEADS FOR MACHINING MUTUALLY PERPENDICULAR FLAT SURFACES

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The paper deals with issues and shows the relevance related to the use of composite milling heads for machining wide flat surfaces. A 3D model of a composite milling head is presented. Shown, the design of the composite milling head with four face mills allows the milling of planes in mutually perpendicular directions. The surface machined with a single pass milling is continuous in width. It allows to shorten the cutting length and machining time, increasing productivity wide flat surfaces by milling.

KEYWORDS

Composite milling head, the direction of working feed, face mill, wide flat surface

1 INTRODUCTION

Flat surfaces are found in almost all parts of machines, and most of them require machining to perform the appropriate functions according to their service purpose [Kotliar 2020]. The quality of flat surfaces determines the performance of many parts and assemblies. Therefore, research in the field of machining flat surfaces is still an urgent task.

For machining flat surfaces, various methods can be used: planing, chiseling, milling, broaching, grinding, scraping, lapping, etc. But in this case are most used in milling, planning, and grinding. Most machine parts do not require such quality indicators that can be obtained by grinding. Therefore, milling and planning remain the most popular in industries. But these two machining methods are fundamentally different in terms of kinematics and the method of shaping flat surfaces.

One of the limitations of the existing methods of chip-type machining of flat metal surfaces is considerable time expenditure. So, planing is a low-efficiency type of surface machining leading to a longer machining cycle. Face milling of flat surfaces can also lead to a longer in-cycle period if the workpiece is very wide and demands many cutting passes.

2 LITERATURE REVIEW

The selection of the rational manufacturing process for surfaces machining depends on numerous criteria, for instance, economic [Ivanov 2021] and quality [Kuric 2020, Ivchenko 2020] indicators, technological issues like as manufacturability [Kolesnyk 2020], accuracy [Karpus 2012, Kolesnyk 2015], productivity [Ivanov 2020] or flexibility [Luscinski 2020], equipment characteristics [Jerzy 2014] and tooling features [Denysenko 2020, Císar 2017], appropriate materials [Osadchiy 2016], etc. In [Yin 2022], performed research of the tightness of flat mating surfaces obtained by face milling based on high-resolution metrology was carried out, and it was established that the direction of milling affects the subsequent performance characteristics. Research [Arizmendi 2019] is devoted to modeling and analysis of surface topography and determination of its roughness obtained during face milling, depending on the geometric parameters of the cutter, beating of its cutting edges, and cutting conditions, with subsequent experimental verification of theoretical results. Also, in the face milling of some materials, it is important to preserve their surface integrity. So in [Oliveira 2021, Saleem 2020] and [Rana 2022], the integrity of nickel superalloys Inconel 625, Inconel 718, and alloy steel AISI 52,100, respectively, are investigated in the process of face milling, depending on tool wear, temperature factors, cutting conditions, flow rate and concentration of coolant liquids. At the same time, in [Saleem 2020], the durability of Wiper inserts is also assessed along the way. In [Pimenov 2018], a methodology for modeling the deviation from flatness during face milling, taking into account the angular displacement of the components of the machine tool system and wear along the flank of the tool, was presented, which allows minimizing the deviation by varying the described parameters. Studies of the influence of technological factors on the state and integrity of the surfaces of machined aluminum workpieces after face milling are presented in detail in [Perez 2018], and the effect of the face mill macrogeometry on the technological characteristics and state of the part is presented in [Borysenko 2019].

A separate area of research is to improve machining productivity and reduce energy costs when using face mills. Namely, in the study [Chen 2019], authors propose an integrated approach to optimizing the cutting tool and cutting conditions to minimize energy consumption and production time in the face milling process based on the characteristics of the energy footprint, considering the flexibility of various cutting tools and cutting parameters. The paper [de Carvalho 2015] proposes a new methodology to reduce productivity losses by incorporating vibration analysis and energy efficiency into the face milling strategy for interrupted cuts. [Padmakumar 2020] is devoted to studying the influence of the cutting edge (K-factor) on forces, surface roughness, cutting power, and productivity in face milling of AISI 4140 steel. An increase in productivity by increasing the permissible values of cutting speeds is presented in [Genga 2020], where the surface hardness of cutting inserts from an NbC-Ni alloy was increased due to rapid sintering with a pulsed electric current and laser surface modification. This made it possible to obtain a self-carbide coating of cutting inserts with a depth of 2.5 µm with a higher hardness than the base material of the insert. Increased productivity is also achieved by increasing the dynamic rigidity of the structural elements of the technological system. In [Xia 2020], the design of a new tool slide for face milling with high dynamic rigidity is presented to improve vibration resistance, which made it possible to increase material removal and productivity by almost 3 times.

Research on the processes of cutting tools wear in face milling operation is also devoted many works. In particular, in [Sun 2020], a comprehensive model of the wear of Sialon ceramic tools for high-speed face milling of cast iron GH4099 is proposed. Under these conditions, the types of failures and tool life curves were obtained for the first time through experimental research.

Therefore, based on the studies discussed above, it has been established that a lot of attention is paid to the problems of productivity and energy consumption in face milling. But at the same time, many issues remain unresolved, in particular, the machining of flat surfaces of large and especially large sizes.

The recommended methods of machining large-sized flat surfaces are dealt with in [Taurit 1981]. It is shown there that face milling is one of the most efficient methods of machining workpiece surfaces. However, the use of large-diameter face mills (e.g. 315 mm, 400 mm, 630 mm) causes a number of difficulties. In particular, face mills of such diameter are quite massive, this complicating their servicing. Another problem is the necessity of using costly equipment with a large diameter spindle [Toporov 1990]. A possible way out is using special composite milling heads (CMH) with an individual electric driver [Kushnirov 1996]. Such heads are characterized by high rigidity and can include one or more face mills [Goncharenko 2015, Dumenko 2017, Krainyak 2012]. As such heads are very efficient, the in-cycle time can be reduced. But the available designs of CMH do not make it possible to mill wide flat surfaces in mutually perpendicular directions.

A promising option for CMH is to use face mills with intersecting cutting trajectories of blades [Kushnirov 2013]. This makes it possible to mill wide flat surfaces of continuous width. This more complicated CMH variant allows turning the spindle unit to change the milling width [Kushnirov 2019].

Therefore, the research aims to develop a milling head that makes it possible to machine-wide flat surfaces in mutually perpendicular directions and reduce the duration of the in-cycle period by reducing the number of cutting passes.

3 RESEARCH METHODOLOGY

Machining of very wide flat surfaces with small diameter face mills demands several cutting passes with displacement. For example, it is impossible to machine a 500 mm wide bank surface with a 315 mm diameter mill in one pass, as after the first pass, there remains a layer of the unmilled surface. It means the necessity of one more pass with the mill displacement towards the unmilled surface to secure the overlapping of the two machined surface sections.

Let's take an example of milling a workpiece flat surface with one face mill (Fig. 1). The face mill with a diameter D_{mill} starts milling the surface of the workpiece *W* in the direction of working feed D_{S1}. The maximum possible milling width B is equal to the mill diameter. Then the direction of the working feed changes by 90 degrees, and the milling of a new section is continued in direction D_{S2}. Similarly, milling is carried out in directions D_{S3} and D_{S4}. Beginning with the position where machining starts in direction D_{S5}, there takes place connection by width between the previously machined section D_{S1} and the being machined section D_{S5}. Then machining is continued in directions D_{S6}, D_{S7}, D_{S8} in the same way. As a result, a completely machined surface of the workpiece was obtained.

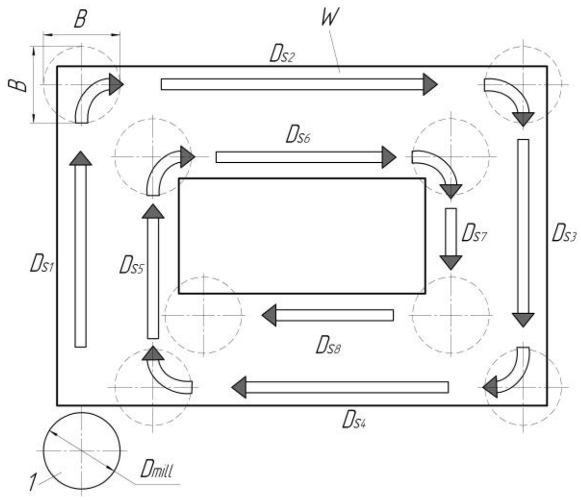

Figure 1. Milling scheme with one face mill: (1) face mill; *W* workpiece; D_{mill} mill diameter; *B* maximum possible milling width; D_{S1}, D_{S2}, D_{S3}, D_{S4}, D_{S5}, D_{S6}, D_{S7}, D_{S8} directions of working feed.

As can be seen from the given example the face mill has to cover a long distance making a lot of passes, until the machining of the workpiece surface is completed. This is conditioned by the fact that the width of machining with one mill is restricted by its diameter. As a result, considerable increase in the machine time and low efficiency, were obtained. To reduce the machine time, a special-design composite milling head that provides one-pass milling of extremely wide surfaces in mutually perpendicular directions, is proposed. The proposed CMH has four spindles with face mills mounted on them, each pair of adjacent milling heads having intersecting trajectories of cutting blades (Fig. 2, Fig. 3). Such heads provide for obtaining a continuous machined surface under relative movement of the workpiece and the machine table in the direction of longitudinal feed and cross-feed. In each pair of adjacent milling cutters one is right-cutting and the other – left-cutting. As it can be seen on the layout (Fig. 2), milling cutters 1 and 3 are right-cutting (rotation direction D_{r1} and D_{r3}) and milling cutters 2 and 4 are left-cutting (rotation direction D_{r2} and D_{r4}).

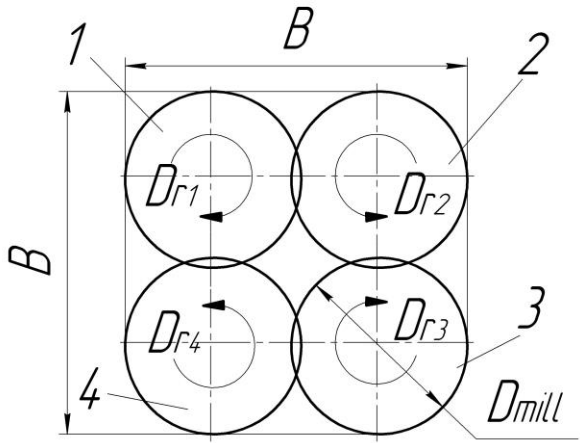

Figure 2. Arrangement of face mills in a four-spindle milling head: (1, 3) right–cutting face mills; (2, 4) left–cutting face mills; D_{mill} mills diameter; D_{r1}, D_{r2}, D_{r3}, D_{r4} directions of spindles rotations; *B* maximum possible milling width.

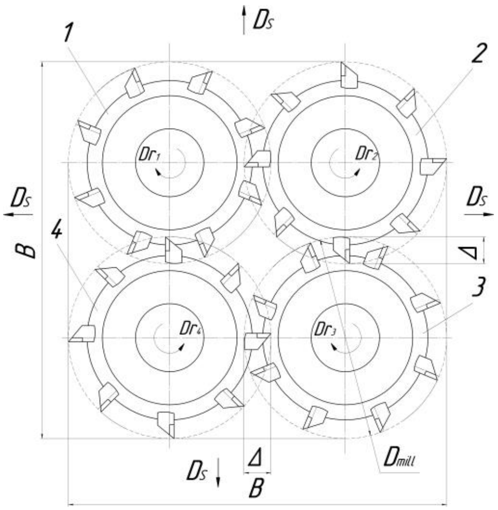

Figure 3. Scheme milling head with four face mills: (1, 3) right–cutting face mills; (2, 4) left–cutting face mills; (3) cutter; *D1, D2, D3, D4* mills diameters; *B* milling width; *Δ* overlap of cutter trajectories; D_s direction of working supply; D_{r1}, D_{r2}, D_{r3}, D_{r4} directions of spindle rotation.

According to Fig. 3 the face mills 1, 2, 3 and 4 are positioned so that the axes of the spindle that support the mills are in a two parallel single plane perpendicular to the working supply in two ways D_s. The cutting inserts 3 of each mill on scheme are between those of the rest mills. This arrangement scheme, using the example of CMH with two face mills, has already been tested in [Kushnirov 2013]. The mills are rotated by an independent drive connected through gear transmissions to the spindles, which turn in directions D_{r1}, D_{r2}, D_{r3} and D_{r4}. In the case of displacement of the milling head with supply D_s relative to the blank one way or the other, milling with width *B* is possible in mutually perpendicular directions.

Fig. 4 shows an example of machining flat surfaces with the proposed milling head. The 4-spindle head, containing four face milling cutters of D_{mill} diameter each, starts milling the surface of the workpiece *W* in working feed direction D_{S1}. The pair of face milling cutters 1 and 2 is involved here. Then the working feed direction is changed by 90 degrees, and the process of milling the workpiece surface in direction D_{S2} with milling cutters 2 and 3 is implemented. Having covered this section, the head working feed direction was again changed by 90 degrees, and begin working in direction D_{S3} with milling cutters 3 and 4. Then follows the next section in direction D_{S4} involving milling cutters 1 and 4.

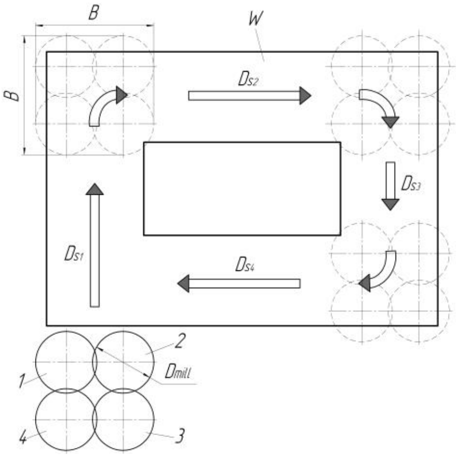

Figure 4. Milling scheme with a four-spindle milling head: (1, 2, 3, 4) four face mills with intersecting cutter trajectories; *W* workpiece; D_{mill} mills diameter; *B* maximum possible milling width; D_{S1}, D_{S2}, D_{S3}, D_{S4} directions of working feed.

The proposed CMH design in the form of a 3D model is shown in Fig. 5. The proposed CMH can be used for machining flat surfaces of workpieces with the maximum milling width *B* equal to twice the diameter of the face milling cutter D_{mill}, minus the value of blade trajectories overlap. Moreover, milling can be realized with any perpendicular movement of the milling head or the workpiece (to the left, to the right, up, down).

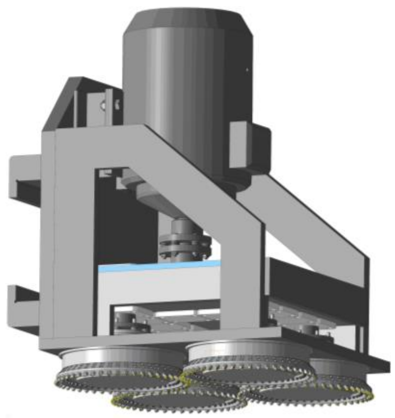

Figure 5. Milling head with four face mills for processing mutually perpendicular flat surfaces (3D model).

So, each pair of adjacent cutters mills its section of the workpiece surface. After having completed milling, the section in direction D_{S4}, completely machined workpiece was obtained.

4 CONCLUSIONS

Comparing the two variants of milling a workpiece surface, represented in Fig. 1 and Fig. 4, the maximum possible milling width *B* is much greater in the second case, represented in Fig. 4. Hence, the proposed design of the milling head makes it possible to reduce both the number of passes and the machine time. In addition, the milling heads' technological potentialities expand, making it possible to mill flat surfaces in mutually perpendicular directions. As a result, using composite milling heads improves the efficiency of machining workpieces with flat surfaces of great width.

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