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THE SOLID CARBIDE END MILL FOR HIGH-PERFORMANCE MACHINING

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Abstract. There are some results of practical application of the solid carbide end mill developed in HALTEC Ltd Company, used for high-performance machining of curved surfaces of workpieces, which have a complex spatial form. It’s shown how to get high-performance machining of curved surfaces with a multidirectional curvature in heat-treatable and high strength Ti alloy Ti-6Al-2Sn-2Zr-2Mo-2Cr-0.15Si [Ti-6-22-22]. The real experience of the implementation of proposed end mill in the technological process of compressor blade machining is described.

Keywords: end mill, difficult-to-cut materials, non-rigid parts, blade, machining performance

1. Introduction

The machining of non-rigid workpieces, which have relatively small volume in large dimensions is a difficult task, which engineering technology is facing at the moment. Due to the high ductility of technological system the high-performance machining of this workpieces is usually impossible. Occurring in the surface layer of the treated parts after its removal from the machine residual stresses are the result of thermal and power intensity of the cutting, which is especially critical for non-rigid parts. Therefore, in practice, specialists are trying to avoid high temperatures and cutting forces in the contact zone of the tool and the workpiece by reducing elements of the cutting conditions.

The most of non-rigid parts which are used in the aircraft industry have a complex spatial shape, including the curved sections which are processed by milling on the multi-axis CNC machines. Their machining is carried out by end mills with spherical or toroidal end face, the choice each time is determined by the capabilities of the equipment, the rigidity of the technological system, the geometric parameters of the specific milling, economic feasibility, etc. The main factor which limits the machining performance and, consequently, the cost of the final product is the small width of the cut, which affects the height of scallops of the machined surface. Obviously, for lowest roughness of the machined surface is important to have the more efficient radius of contact of the tool and workpiece, a small step between two successive passages and minimum level of runout of the tool.

But with decrease of the step the machining time substantially increases. At the same time increase of the effective radius is currently achieved by using larger end mill diameter that respectively increases the radius of the spherical section or the radius of the torus. It is known that the minimum roughness of the machined surface is achieved by the use of solid carbide end mills, but the use of such tools with a diameter bigger than 32 mm is not economically feasible due to their high cost.

Thus, all the cutting elements of the end mill (with ball or toroidal end face) – the radius, end face and peripheral teeth may take part in cutting, although it should be noted that the machining of complex curved surfaces where the depth of cut is relatively small, only the radius of end mill participates in cutting.

Thus, the development of the end mill which combines the advantages of spherical and toroidal-shaped end and is capable of leading high-performance machining of non-rigid parts is an urgent task.

2. Main part

The new end mill which combines two curved area – R_B and R_T and $R_B > R_{SHANK}$ and was developed in HALTEC Ltd (Ulyanovsk, Russia) [1, 2, 3] is shown on Fig. 1. This end face design can significantly increase the effective diameter of the contact between the end mill and the workpiece, thereby significantly increasing the spacing between successive passes for high productivity.

A distinctive feature of the proposed end mill is the presence of the flat section *W* which is perpendicular to the axis of rotation (Wiper) and further cuts the scallops after consecutive passes. Sandvik Coromant (Sweden) was the first company to use Wiper technology for machining for turning inserts T-max series. It's known that the use of inserts with Wiper geometry allows doubling the feed while maintaining high-altitude surface roughness or halving these parameters while maintaining feed. Later skills with turning inserts with Wiper geometry were extended to the milling inserts. Also tool companies proposed to install the additional wiper insert on the cutter.

Wiper application section on the solid carbide tool is performed for the first time.

Furthermore, the proposed end mill has a dish angle *d* to prevent friction of the end face teeth and machining surface.

Thus, in general case, the proposed mill is characterized by two radius sections R_B and R_T, the flat section *W* and dish angle *d* (Fig. 2 a-c).

The basic ability to cut curvilinear surfaces of the workpiece on the example of milling titanium alloy Ti-6-22-22 is shown on Fig. 3 a) and b). The essence of the test is the milling of a curved convex and concave surface by the end face of the tool. The workpiece was fixed in machine grip SCHUNK KSG125 and was machined with using of SGS Tool Company end mill (series ZAPCR, Art. Number 42722, the utting diameter D = 20 mm, the corner radius Rt = 3 mm, the cutting length Lcut = 38 mm) and also with using of HALTEC proposed end mill (series HFM, type 3, the cutting diameter D = 20 mm, the corner radius Rtor=3 mm, the ball section radius Rb = 15 mm, the cutting length Lcut = 38 mm).

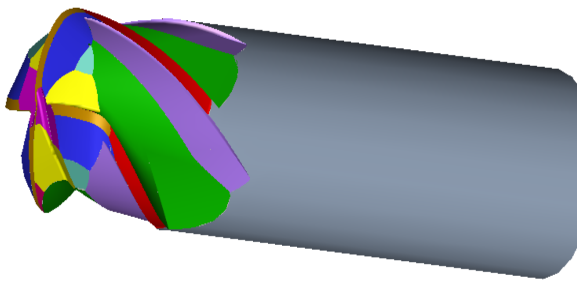

Fig. 1. 3D model of the proposed end mill in the window of WALTER Helitronic Tool Studio software

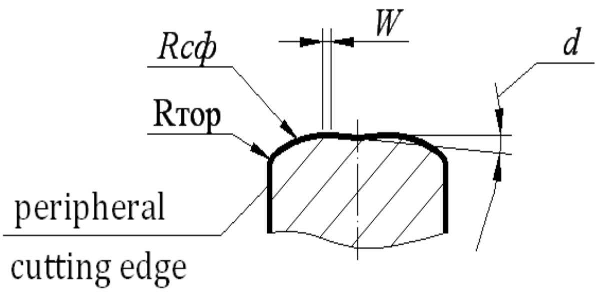

Fig. 2, a) Variant 1 of end face

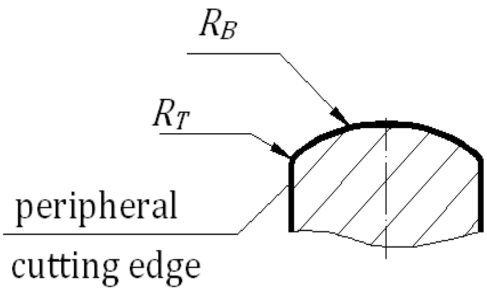

Fig. 2, b) Variant 2 of end face

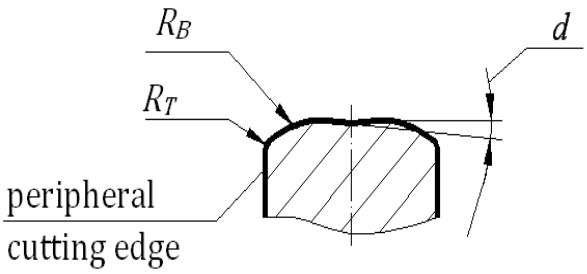

Fig. 2, c) Variant 3 of end face

Practical recommendations how to use the proposed end mill for machining are shown in the Table.

Table 1
Recommendations for use of the proposed end mill series HFM

Type of machining	Variant of end face from Fig. 2		
	1	2	3
Rough curved surfaces milling	0	+	+
Rough plane milling	+	0	+
Finish curved surfaces milling	–	+	+
Finish plane milling	+	–	–

«+» – recommended; «0» – permissible; «–» – not recommended

Fig. 3, a) Test piece

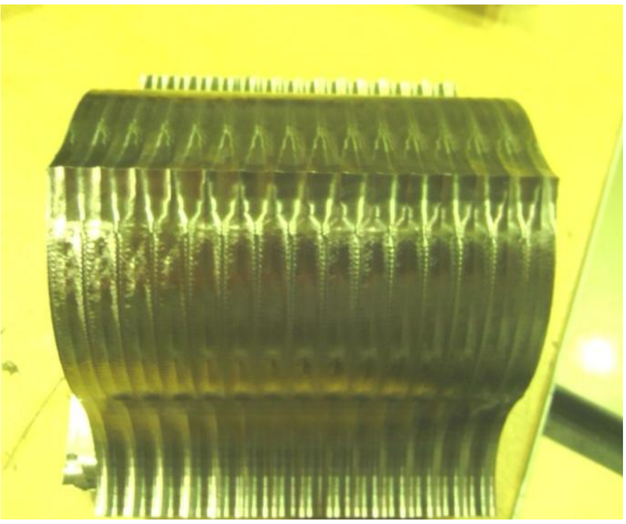

Fig. 3, b) Test piece after machining by proposed end mill

The cutting conditions: the depth of cut ap = 1.7 mm; the width of cut ae = 7mm; cutting speed Vc = 40m/min; the feed per tooth fz = 0,5 mm.

SGS end mill was broken after 6 minutes of machining (Fig 4, a). HALTEC end mill kept possibility to work after 2 hours (Fig. 4, b)

In addition, the power intensity of the cutting by the proposed end mill is about 40% lower than the SGS end mill (Fig. 5).

The practical value of the proposed end mill is the possibility of significant increase of the blade machining performance.

The aim is to achieve the maximum performance with satisfactory quality of the machined surface and tool life for milling operation profile of the blade of compressor turbine engines. Used workpiece is stamping of the titanium alloy TiAl6V with 2 mm allowance on each side.

Fig. 4, a) SGS end mill series ZAPCR after 6 minutes machining

Fig. 4, b) HALTEC end mill series HFM after 120 minutes machining

Workpiece clamping is carried out for the pre-treated surface of the blade lock in a specially designed device which is mounted on the faceplate, clamped in a self-centering three-jaw chuck of the MAZAK Integrex i-200 machining center. From the side of the shank the workpiece is pressed by the rear center with a force of 200 N (Fig. 6).

According to the accepted and proven technology, it is necessary to leave allowance for subsequent finish milling of 0.3 mm.

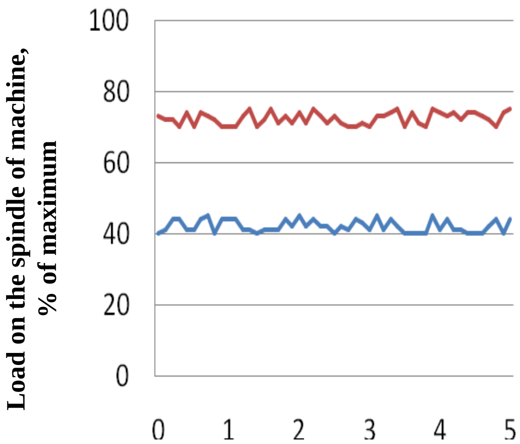

Fig. 5. Specific power intensity of the milling of the test piece. The time interval of 5 seconds is shown (steady cutting).

The modern technological process of machining of similar parts uses semi-finishing and finishing five-axis milling in one setup. According to the results of the used NC-program the semi-finishing blade machining carried by toroidal end mill of SGS Tool Company (series ZAPCR, Art. Number 42722) was described earlier. The cutting conditions for reasonable tool life with satisfactory surface quality are: the cutting speed Vc = 40m/min; the feed per tooth fz = 0,06 mm; the depth of cut ap = 2 mm; the width of cut ae = 3 mm. Under such conditions, the machining time of semi-finishing blade profile operation was 27 minutes. Tool life until 0.3 mm flank wear is 108 minutes or four parts.

The exterior view of the workpiece after semi-finishing blade milling is shown in Fig. 7.

Using of the proposed original end mill allowed to increase the feed more than 3 times – up to 0.2 mm / tooth with increasing the cutting width from 3 to 7 mm and reduces machining time to 5 minutes. It was noted that the smoother machining was, the much less vibration and the better surface quality by reducing the height of scallops was. After machining of 20 workpieces the proposed end mill kept possibility to work: spalling and chipping on the cutting edge is not detected. So, further increase of the cutting feed is impractical due to low rigidity of the technological system.

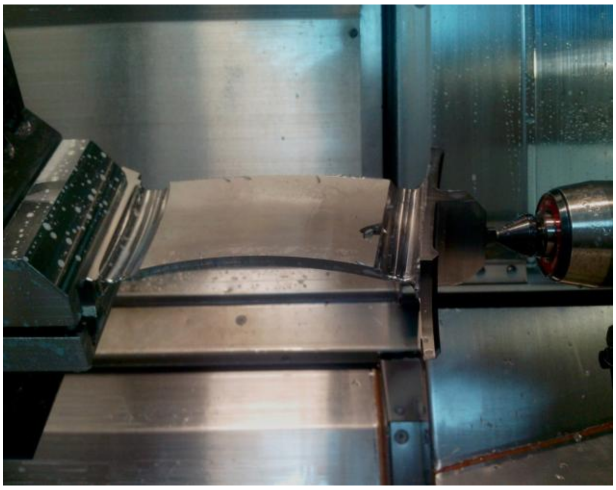

Fig. 6. Blade workpiece in the machine device

Fig. 7. Exterior view of the workpiece after semi-finishing blade milling

3. Conclusion

Thus, the effectiveness of the proposed end mill in the machine parts production, in particular, for complex spatial form of difficult-to-cut materials, which often are used in high-tech sectors of the industry was experimentally validated.

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