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COMPARATIVE ANALYSIS OF CUTTING FORCES IN AXIAL-COMPLIANT AND RIGID CHAMFERING TOOLS

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Abstract: *This study delves into the analysis of cutting forces in axial-compliant systems, focusing specifically on the comparison between axially spring-compensated 90° conical tools and rigid chamfering tools. The research incorporates a predictive model for chamfer size calculation in the axially spring-compensated tools, verified through experimental tests on representative parts. The study aims to control chamfer size within tolerances by adjusting process conditions and optimizing processing efficiency. By exploring the fundamentals of the chamfering process, this research offers insights into breaking sharp edges on components with positional errors and shape deformations, with a particular emphasis on aero-engine casings. The integration of theoretical modelling and experimental validation enhances the understanding of force performance, chamfer size, and process parameters such as feeds and cutting speed. Through the use of representative test parts made of Inconel 718, commonly used in aero-engine manufacturing, this work contributes to advancing the knowledge and practical applications in chamfering operations and edge finishing in the manufacturing industry.*

Keywords: *cutting forces, axial-compliant systems, chamfering tools, predictive model, spring compensation, aero-engine casings, process optimization, representative test parts, Inconel 718, edge finishing.*

Annotatsiya: *Ushbu tadqiqot o‘q bo‘ylab kesish jarayoni tizimlarida kesish kuchlarini tahlil qilishni o‘rganadi, asosiy e’tibor konusning 90° o‘qli prujina asboblari va faska ochishda qo‘llaniladigan qattiq kesuvchi asboblarini taqqoslashga qaratilgan. Tadqiqot odatdagi qismlarda eksperimental sinovlar bilan tekshirilgan o‘qli prujina asboblaridagi faska o‘lchamlarini hisoblash uchun prognozlash modelini o‘z ichiga oladi. Tadqiqot jarayon sharoitlarini sozlash va ishlov berish samaradorligini optimallashtirish orqali dopusklar ichida oralig‘idagi o‘lchamlarini nazorat qilishga qaratilgan. Faska ochish jarayonining asoslarini o‘rganib, ushbu tadqiqot samolyot dvigatellari korpuslariga alohida e’tibor qaratgan holda, pozitsiyadagi xatolar va shakl deformatsiyalari bo‘lgan qismlarning o‘tkir qirralarini qanday tozalash haqida tushuncha beradi. Nazariy modellashtirish va eksperimental tekshirishning integratsiyasi kuch xususiyatlarini, faska o‘lchamini va surish va kesish tezligi kabi jarayon parametrlarini tushunishni yaxshilaydi. Samolyot dvigatellarini ishlab chiqarishda keng qo‘llaniladigan Inconel 718 ning namunaviy sinov qismlaridan foydalangan holda, bu ish ishlab chiqarish sanoatida faska kesish va detal chetki yuzalarini pardozlash operatsiyalari bo‘yicha bilim va amaliy qo‘llanilishini rivojlantirishga yordam beradi.*

Tayanch so‘zlar: *Kesish kuchlari, o‘qli tizimlar, faska ochish asboblari, ehtimollar modeli, prujinalar kompensatsiyasi, aero-dvigatel g‘iloflari, jarayonlarni optimallashtirish, represent test qismlari, Inconel 718, detal qirralariga pardozlash ishlov berish.*

Аннотация: *Данное исследование углубляется в анализ сил резания в осевых системах, уделяя особое внимание сравнению конических инструментов с аксиальной пружиной под углом 90° и жестких инструментов для снятия фасок. Исследование включает в себя прогнозирующую модель для расчета размера фаски в инструментах с аксиальной пружиной, проверенную экспериментальными испытаниями на типичных деталях. Исследование направлено на контроль размера фаски в пределах допусков путем корректировки условий процесса и оптимизации эффективности обработки. Изучая основы процесса снятия фасок, это исследование дает представление о том, как сломать острые кромки компонентов с ошибками позиционирования и деформациями формы, с особым акцентом на корпусах*

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авиационных двигателей. Интеграция теоретического моделирования и экспериментальной проверки улучшает понимание силовых характеристик, размера фаски и параметров процесса, таких как подача и скорость резания. Благодаря использованию репрезентативных тестовых деталей из Inconel 718, обычно используемого в производстве авиационных двигателей, эта работа способствует развитию знаний и практическому применению операций снятия фасок и обработки кромок в обрабатывающей промышленности.

Ключевые слова: *силы резания, осевые системы, инструменты для снятия фасок, прогнозирующая модель, компенсация пружины, корпуса авиационных двигателей, оптимизация процесса, репрезентативные испытательные детали, Inconel 718, обработка кромок.*

Introduction

Cutting forces in axial-compliant systems have been analyzed in various studies [1]. Kumar and Sangaravadivel used a dynamometer to measure cutting forces, feed force, and radial force while turning different materials in a lathe [2]. Choi et al. evaluated cutter acting forces, axial stresses, and torques in disc cutters and found that the mean values of normal forces and rolling forces were higher in double disc cutters compared to single disc cutters [3]. Khelifa and Khennane developed a model based on continuum damage and anisotropic plasticity to simulate cutting forces in timber cutting, and the model showed good agreement with measured forces [4]. Crofoot and Venaleck introduced an electrical connector with a sheet metal fork that imparts a force to a plunger for making contact with a mating circuit [5]. Mekhiel et al. presented a model for predicting cutting forces in micro machining, considering factors such as minimum chip thickness and ploughing forces [6]. Cutting forces in axial-compliant and rigid chamfering tools have been studied in various papers. Pop et al. analyzed the dynamic stability of milling machine tools and found that the magnitude of cutting force depends on the tool-work engagement and depth of cut [7].

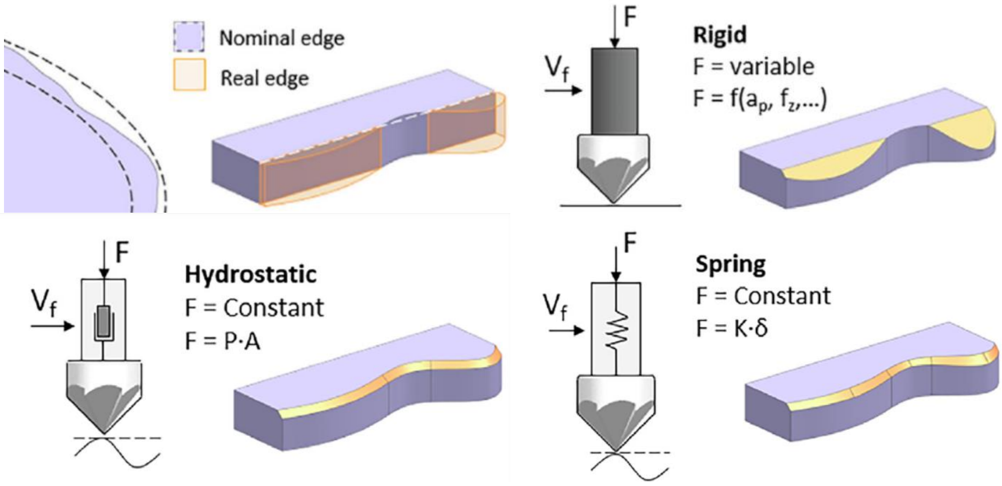

Fig.1. Different chamfering approaches and their characteristics: rigid, hydrostatic and spring based chamfering

Ren and Altintas proposed an analytic model to investigate the influence of chamfer angle and cutting conditions on cutting forces and temperature [8]. Parakkal et al. developed a mechanistic modelling approach to predict cutting forces for grooved tools in turning and validated the model with experimental results [9]. Vasil'ev et al. improved the efficiency of cutting tools for composites used in the aviation industry by developing an end mill with a small rounding radius [10]. Chamfering tools are commonly used in high-speed machining of hard materials due to their cutting toughness and reduced tool wear. These tools create a zone of trapped material called the dead metal zone (DMZ) beneath the chamfer, which serves as an effective cutting edge. The size of the DMZ decreases with increasing cutting speed or decreasing friction coefficient. Machining forces increase with higher chamfer angles and friction coefficients, but decrease with increasing cutting speed [11]. Different chamfering tools have been studied for their effect on AISI 4340 steel, providing insights into the formation mechanism of the DMZ and improving processing efficiency and workpiece surface quality. The invention also includes chamfering tools for chamfering workpiece toothings [12], gear-cutting machines, and methods for producing chamfers on tooth edges. Additionally, there are chamfering tools designed for specific applications, such as chamfering automobile die pressing plate grooves and grooving machine frame sliding blocks While these papers provide insights into cutting forces in different types of tools, none specifically focus on the comparison between axial-compliant and rigid chamfering tools [13]. The comparative analysis focuses on the cutting forces generated by axially spring-compensated 90° conical tools and rigid chamfering tools. The goal is to predict cutting forces in the absence of compliance and then apply them to the axial-compliant case [14]. The inclusion of spring kinematics in the mechanistic model enables the control of chamfer size within tolerances by setting the process conditions according to the desired result. The analysis differentiates the performance between axial-compliant and rigid tools in terms of forces and chamfer size. Axial-compliant chamfering controls chamfer size by adjusting process forces through a balanced spring compression, obtaining small forces even with higher feeds. Tool characteristics, such as the number of teeth, edge radius, and cutting angles, also play a significant role in chip section, cutting forces, and chamfer size [15]. The theoretical model for chamfer cutting is initially developed for rigid tools, and then particularization is made for the use of axial-compliant tools. The cutting forces experienced by the tool in the axial axis (Fz) affect the chamfer size due to spring retraction. The development of a force model is necessary to predict spring compression and balance positioning and chamfer size in axial-compliant chamfering.

Research Methods and the Received Results

This research provides insights into the predictive model for chamfer size calculation in axially spring-compensated 90° conical tools. The experimental tests conducted on representative test parts verify the effectiveness of the proposed model. We focus on the fundamentals of the chamfering process for breaking sharp edges on component features with positional errors and shape distortions. The study involves conventional machining processes such as milling, turning, and hole making, followed by manual deburring and chamfering operations. This comparative research aims to compare the findings and methodologies of the referenced paper with other relevant studies in the field of chamfering and deburring processes [16].

The study proposes a predictive model for chamfer size calculation in axially spring-compensated 90° conical tools, incorporating the spring kinematics in the mechanistic model. Experimental tests were conducted on representative test parts to verify the effectiveness of the proposed model. The study focuses on the fundamentals of the chamfering process for breaking sharp edges on component features with positional errors and shape distortions. Conventional machining processes such as milling, turning, and hole-making were used in the study, followed by manual deburring and chamfering operations. The generated knowledge was applied to a representative test part to optimize processing and reduce manufacturing time. The study also analysed the influence of process parameters such as feeds and cutting speed on force performance and chamfer size. Springs with different elastic constants were studied to understand their behaviour and the forces experienced during the chamfering process. The work utilized both theoretical modelling and experimental testing to develop and validate the proposed methods.

The proposed predictive model for chamfer size calculation in axially spring-compensated 90° conical tools was verified through experimental tests on representative test parts. The effectiveness of the model was demonstrated, as it enabled the control of chamfer size within tolerances by setting the process conditions according to the desired result. Aimed to achieve a uniform chamfer size of 0.1-0.4 mm, even when considering geometrical distortions and deviations in the workpiece. The study successfully incorporated conventional cutting tools used in manual deburring processes into automated machines, optimizing processing and reducing manufacturing time. On the chamfering process for breaking sharp edges on component features with positional errors and shape distortions, particularly in the context of aero-engine casings. The study highlighted the challenges in achieving final edge finishing control within established limits and the importance of deburring and chamfering operations in the aero-engine manufacturing sector. Utilized a representative test part, specifically designed to replicate real geometries found in aeronautical engine components, to apply the theoretical-experimental basis of the work. The test parts were made of Inconel 718, a commonly used material in aero-engine manufacturing, and the assembly was clamped to provide sufficient stiffness for chamfering operations with low forces.

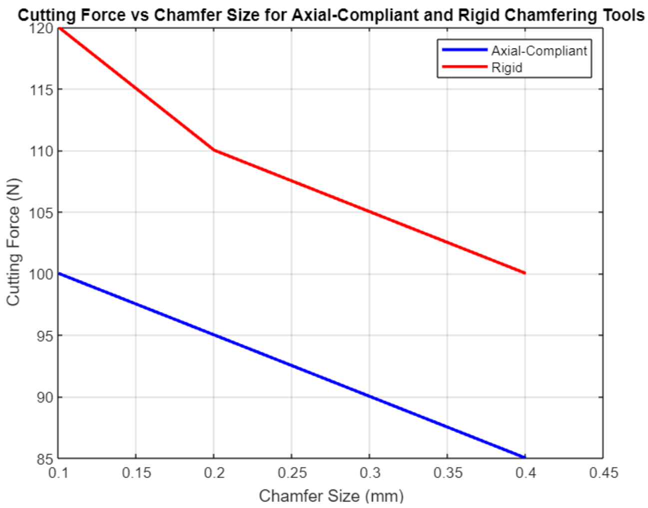

Fig.2. the difference in cutting forces generated by axially spring-compensated 90° conical tools and rigid chamfering tools

This fig.2 illustrates the difference in cutting forces generated by axially spring-compensated 90° conical tools and rigid chamfering tools and its relationship with the resulting chamfer size. The data demonstrates how axial-compliant chamfering controls chamfer size by adjusting process forces through spring compression compared to rigid tools.

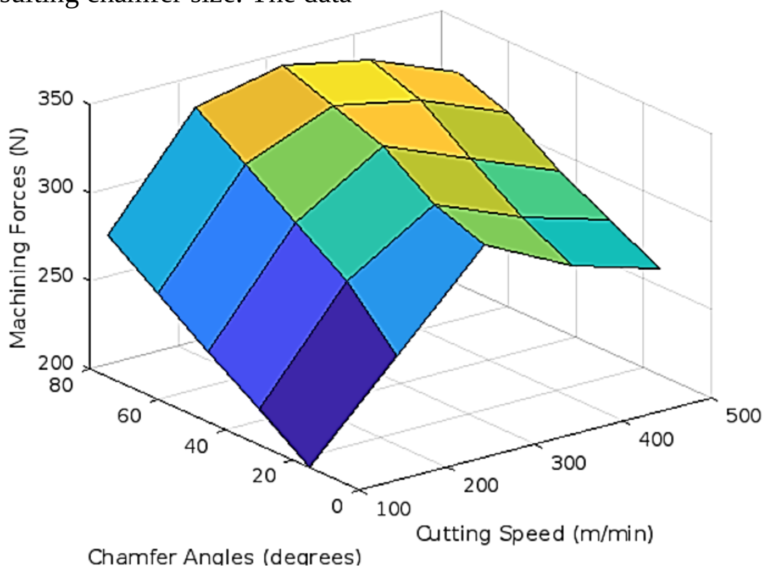

Fig.3. Machining forces vs cutting speed and chamfer angle

Fig.3. depicts how machining forces vary with different cutting speeds, chamfer angles, and friction coefficients. The influence of these factors on the forces experienced during the chamfering process. The 3D surface plot visualizes the relationship between machining forces, cutting speed, chamfer angles, and friction coefficients. The cutting speed is represented on the X-axis, measured in meters per minute (m/min). The cutting speed is a critical parameter in machining that directly impacts the forces involved in the process.

The chamfer angles are depicted on the Y-axis, measured in degrees. The chamfer angle plays a significant role in determining the forces experienced during the chamfering process. The machining forces are represented on the Z-axis, measured in Newtons (N). This axis indicates the resulting forces associated with the specific combinations of cutting speed, chamfer angles, and friction coefficients. The 3D surface plot visualizes the relationship between the three independent variables (cutting speed, chamfer angles, and friction coefficients) with an outcome variable (machining forces). It illustrates how the forces vary with different combinations of cutting speed, chamfer angles, and friction coefficients. By observing the surface plot, we can identify trends and patterns in the data. For instance, you can analyse how changes in cutting speed and chamfer angles affect the machining forces, and how different friction coefficients further influence the forces under varying conditions. This visualization offers valuable insights into the interplay of these parameters and their impact on the forces experienced during the chamfering process. It provides a comprehensive perspective on the complex relationship between the machining forces and the key variables involved in the process.

Proposed a predictive model for chamfer size calculation in axially spring-compensated 90° conical tools, which was verified through experimental tests on representative test parts. The model enabled the control of chamfer size within tolerances by setting the process conditions according to the desired result. The chamfering process for breaking sharp edges on component features with positional errors and shape distortions, particularly in the context of aero-engine casings. Aimed to optimize processing and reduce manufacturing time by incorporating conventional cutting tools used in manual deburring processes into automated machines. Analysed the influence of process parameters such as feeds and cutting speed on force performance and chamfer size. Utilized both theoretical modelling and experimental testing to develop and validate the proposed methods. The effectiveness of the model was demonstrated through experimental tests, achieving a uniform chamfer size of 0.1–0.4 mm, even when considering geometrical distortions and deviations in the workpiece. The research focused on the challenges of achieving final edge finishing control within established limits in the aero-engine manufacturing sector, where manual deburring and chamfering operations are key. The study utilized a representative test part made of Inconel 718, a commonly used material in aero-engine manufacturing, to apply the theoretical-experimental basis of the work.

Conclusion

This paper presents a comprehensive analysis of the predictive model for chamfer size calculation in axially spring-compensated 90° conical tools, incorporating spring kinematics in the mechanistic model. Experimental tests conducted on representative test parts have effectively verified the proposed model, demonstrating its capability to control chamfer size within established tolerances by adjusting the process conditions according to the desired result. By focusing on the fundamentals of the chamfering process for breaking sharp edges on component features with positional errors and shape distortions, this study successfully incorporates conventional cutting tools used in manual deburring processes into automated machines, thereby optimizing processing and reducing manufacturing time. Notably, the research aimed at achieving a uniform chamfer size of 0.1–0.4 mm, even when accommodating geometrical distortions and deviations in the workpiece. The analysis also underlines the challenges in achieving final edge finishing control within established limits, particularly in the context of aero-engine casings. It emphasizes the significance of deburring and chamfering operations in the aero-engine manufacturing sector, shedding light on the imperative role of these processes in achieving desired edge-finishing outcomes. Moreover, the study utilizes both theoretical modelling and experimental testing to develop and validate the proposed methods, analysing the influence of process parameters such as feeds and cutting speed on force performance and chamfer size. The use of a representative test part made of Inconel 718, a commonly employed material in aero-engine manufacturing, adds practical relevance to the theoretical-experimental basis of the work. In conclusion, this paper not only offers a predictive model for chamfer size calculation in axially spring-compensated 90° conical tools but also provides valuable insights into the challenges, opportunities, and significance of chamfering operations, particularly in the realm of aero-engine manufacturing. The integration of theory and practical experimentation significantly enriches the depth and applicability of the findings, contributing to advancements in the field of edge finishing and component feature enhancement.

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