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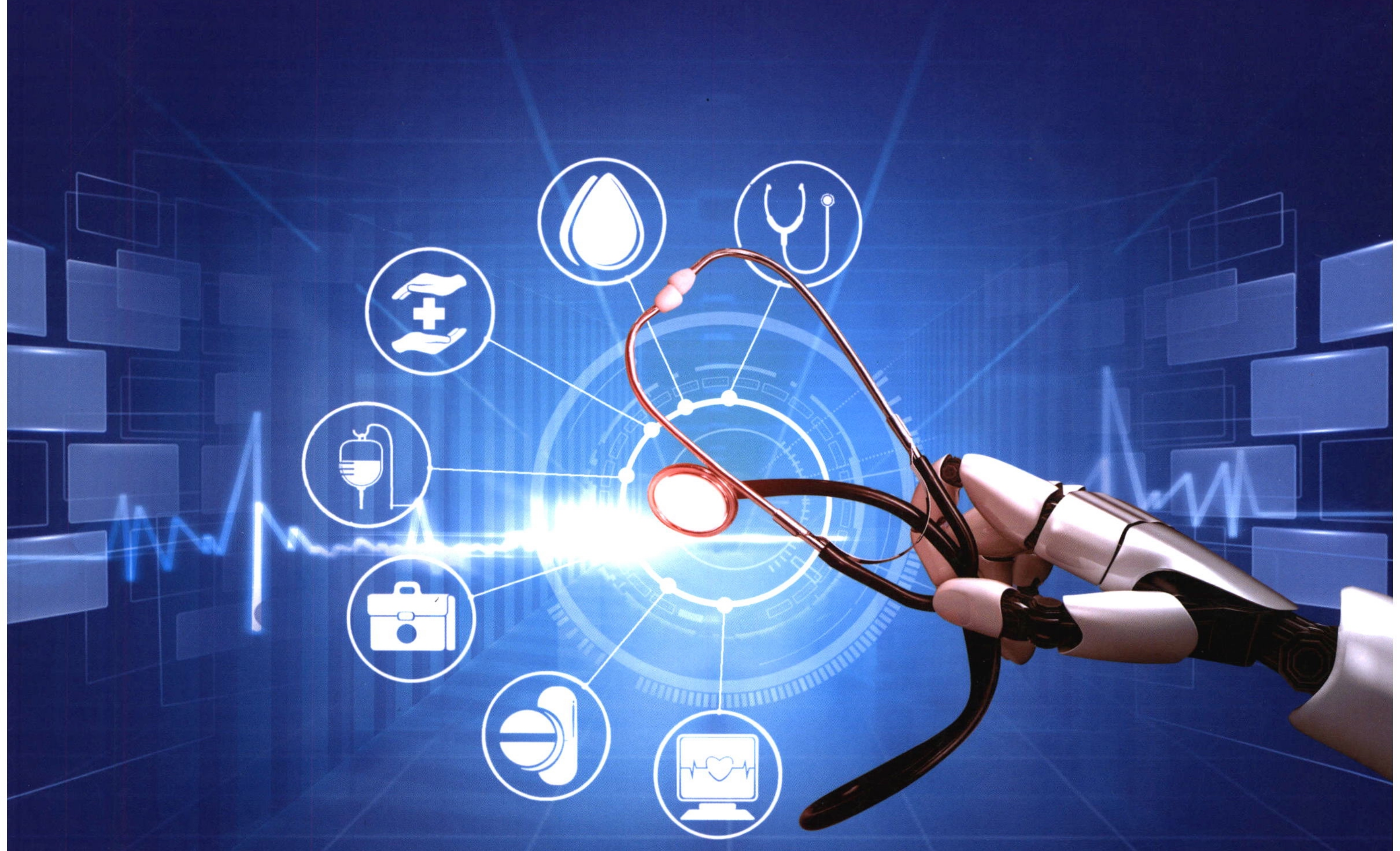

Special Issue on Healthcare Mechatronics
Guest Editor: Yan Shi, Qing Guo and Bin Zhang

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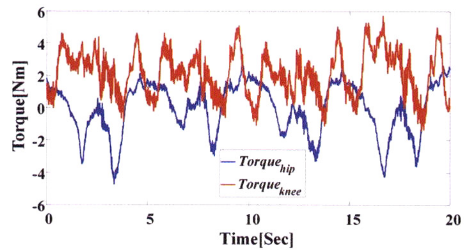
CONTENTS

Vol. 34, No. 1, February, 2021

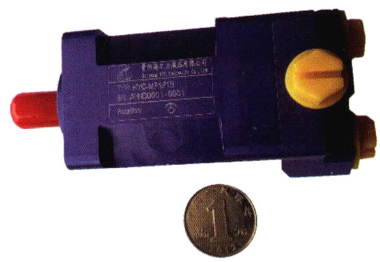
CHINESE JOURNAL OF MECHANICAL ENGINEERING

Special Issue on Healthcare Mechatronics

Abstract: In this study, a humanoid prototype of 2-DOF (degrees of freedom) lower limb exoskeleton is introduced to evaluate the wearable comfortable effect between person and exoskeleton. To improve the detection accuracy of the human-robot interaction torque, a BPNN (backpropagation neural networks) is proposed to estimate this interaction force and to compensate for the measurement error of the 3D-force/torque sensor. Meanwhile, the backstepping controller is designed to realize the exoskeleton's passive position control, which means that the person passively adapts to the exoskeleton. On the other hand, a variable admittance controller is used to implement the exoskeleton's active follow-up control, which means that the person's motion is motivated by his/her intention and the exoskeleton control tries best to improve the human-robot wearable comfortable performance. To improve the wearable comfortable effect, serval regular gait tasks with different admittance parameters and step frequencies are statistically performed to obtain the optimal admittance control parameters. Finally, the BPNN compensation algorithm and two controllers are verified by the experimental exoskeleton prototype with human-robot cooperative motion.



Abstract: The hydraulic exoskeleton is one research hotspot in the field of robotics, which can take heavy load due to the high power density of the hydraulic system. However, the traditional hydraulic system is normally centralized, inefficient, and bulky during application, which limits its development in the exoskeleton. For improving the robot's performance, its hydraulic actuating system should be optimized further. In this paper a novel hydraulic actuating system (HAS) based on electric-hydrostatic actuator is proposed, which is applied to hip and knee joints. Each HAS integrates an electric servo motor, a high-speed micro pump, a specific tank, and other components into a module. The specific parameters are obtained through relevant simulation according to human motion data and load requirements. The dynamic models of the HAS are built, and validated by the system identification. Experiments of trajectory tracking and human-exoskeleton interaction are carried out, which demonstrate the proposed HAS has the ability to be applied to the exoskeleton. Compared with the previous prototype, the total weight of the HAS in the robot is reduced by about 40%, and the power density is increased by almost 1.6 times.



CONTENTS

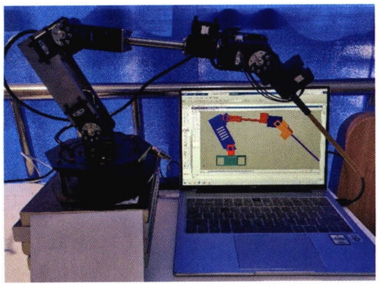
Vol. 34, No. 1, February, 2021

(2021)34:25

DOI: 10.1186/s10033-021-00534-x

Control Performance Evaluation of Serial Urology Manipulator by Virtual Prototyping

Hu Shi • Jiajie Li • Lianjie Guo • Xuesong Mei



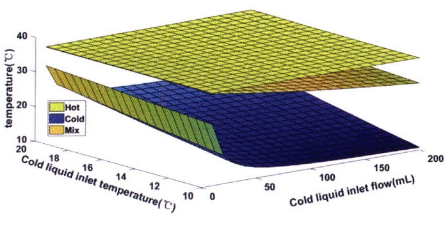
Abstract: Prostatic hyperplasia and tumor are common diseases, and the minimally invasive surgery inserting the instruments through the urethra into the prostate is commonly conducted. Taking the robotic manipulator for such surgery into consideration, this paper analyses the workspace of the end effector, and proposes the distribution error of the fixed point and the tracking error of manipulator end effector on the cone bottom surface of the workspace as the basis for control implementation of the manipulator. The D-H coordinate system of the manipulator is established and the trajectory planning of the end effector in the Cartesian space is carried out. The digital model was established, and dynamics simulation was performed in Solidworks and Matlab/Simulink environment to guide the manipulator design. Trajectory mapping and synchronization control between virtual model and the actual manipulator are realized based on digital twin technique. The virtual manipulator can reflect the real-time state of the manipulator with data interaction by comparing the dynamics simulation results with the motor current values obtained by experiment. Experiment was carried out with PD feedback control and Newton-Euler dynamics based feedforward control to get the trajectory tracking characteristic of each motor, errors of the fixed point and tracking performance of the end effector of the manipulator. The results show that compared with PD feedback control, feed forward control implementation can achieve a reduction of 30.0% in the average error of the fixed point of the manipulator and a reduction of 33.3% in the maximum error.

(2021)34:23

DOI: 10.1186/s10033-021-00541-y

Modeling and Simulation of an Invasive Mild Hypothermic Blood Cooling System

Na Wang • Qinghua Liu • Yan Shi • Shijun Wang • Xianzhi Zhang • Chengwei Han • Yixuan Wang • Maolin Cai • Xunming Ji



Abstract: Nowadays, mild hypothermia is widely used in the fields of post-cardiac arrest resuscitation, stroke, cerebral hemorrhage, large-scale cerebral infarction, and craniocerebral injury. In this paper, a locally mixed sub-low temperature device is designed, and the cold and hot water mixing experiment is used to simulate the human blood transfer process. To set a foundation for the optimization of the heat transfer system, the static characteristics are analyzed by building the mathematic model and setting up the experimental station. In addition, the affection of several key structure parameters is researched. Through experimental and simulation studies, it can be concluded that, firstly, the mathematical model proved to be effective. Secondly, the results of simulation experiments show that 14.52 °C refrigeration can reduce the original temperature of 33.42 °C to 32.02 °C, and the temperature of refrigerated blood rises to 18.64 °C, and the average error is about 0.3 °C. Thirdly, as the thermal conductivity of the vascular sheath increases, the efficiency of the heat exchange system also increases significantly. Finally, as the input cold blood flow rate increases, the mass increases and the temperature of the mixed blood temperature decreases. It provides a research basis for subsequent research on local fixed-point sub-low temperature control technology.

Review

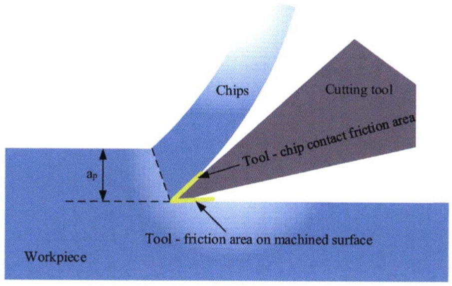
(2021)34:18

DOI: 10.1186/s10033-021-00536-9

Milling Force Model for Aviation Aluminum Alloy: Academic Insight and Perspective Analysis

Zhenjing Duan • Changhe Li • Wenfeng Ding • Yanbin Zhang • Min Yang • Teng Gao • Huajun Cao • Xuefeng Xu • Dazhong Wang • Cong Mao • Hao Nan Li • Gupta Munish Kumar • Zafar Said • Sujan Debnath • Muhammad Jamil • Hafiz Muhammad Ali

Abstract: Aluminum alloy is the main structural material of aircraft, launch vehicle, spaceship, and space station and is processed by milling. However, tool wear and vibration are the bottlenecks in the milling process of aviation aluminum alloy. The machining accuracy and surface quality of aluminum alloy milling depend on the cutting parameters, material mechanical properties, machine tools, and other parameters. In particular, milling force is the crucial factor to determine material removal and workpiece surface integrity. However, establishing the prediction model of milling force is important and difficult because milling force is the result of multiparameter coupling of process system. The research progress of cutting force model is reviewed from three modeling methods: empirical model, finite element simulation, and instantaneous milling force model. The problems of cutting force modeling are also determined. In view of these problems, the future work direction is proposed in the following four aspects: (1) high-speed milling is adopted for the thin-walled structure of large aviation with large cutting depth, which easily produces high residual stress. The residual stress should be analyzed under this particular condition. (2) Multiple factors (e.g., eccentric swing milling parameters, lubrication conditions, tools, tool and workpiece deformation, and size effect) should be considered comprehensively when modeling instantaneous milling forces, especially for micro milling and complex surface machining. (3) The database of milling force model, including the corresponding workpiece materials, working condition, cutting tools (geometric figures and coatings), and other parameters, should be established. (4) The effect of chatter on the prediction accuracy of milling force cannot be ignored in thin-walled workpiece milling. (5) The cutting force of aviation aluminum alloy milling under the condition of minimum quantity lubrication (mql) and nanofluid mql should be predicted.



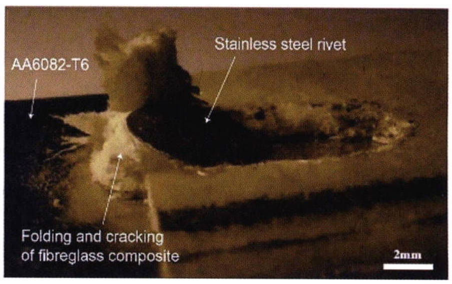
(2021)34:2

DOI: 10.1186/s10033-020-00526-3

An Overview of Self-piercing Riveting Process with Focus on Joint Failures, Corrosion Issues and Optimisation Techniques

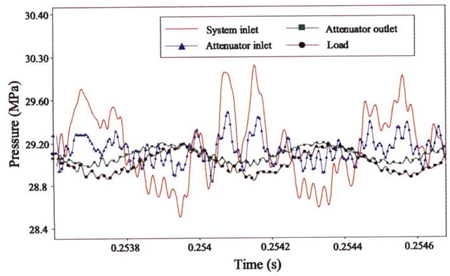
Hua Qian Ang

Abstract: Self-piercing riveting (SPR) is a cold forming technique used to fasten together two or more sheets of materials with a rivet without the need to predrill a hole. The application of SPR in the automotive sector has become increasingly popular mainly due to the growing use of lightweight materials in transportation applications. However, SPR joining of these advanced light materials remains a challenge as these materials often lack a good combination of high strength and ductility to resist the large plastic deformation induced by the SPR process. In this paper, SPR joints of advanced materials and their corresponding failure mechanisms are discussed, aiming to provide the foundation for future improvement of SPR joint quality. This paper is divided into three major sections: 1) joint failures focusing on joint defects originated from the SPR process and joint failure modes under different mechanical loading conditions, 2) joint corrosion issues, and 3) joint optimisation via process parameters and advanced techniques.



CONTENTS

Vol. 34, No. 1, February, 2021



(2021)34:14
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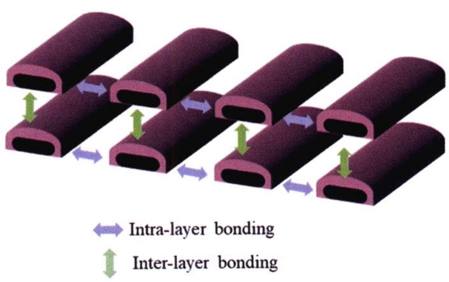
Research Status, Critical Technologies, and Development Trends of Hydraulic Pressure Pulsation Attenuator

Yan Wang • Tongsheng Shen • Chunsen Tan • Jian Fu • Shengrong Guo

Abstract: Hydraulic pumps are a positive displacement pump whose working principle causes inherent output flow pulsation. Flow pulsation produces pressure pulsation when encountering liquid resistance. Pressure pulsation spreads in the pipeline and causes vibration, noise, damage, and even pipeline rupture and major safety accidents. With the development of airborne hydraulic systems with high pressure, power, and flow rate, the hazards of vibration and noise caused by pressure pulsation are also amplified, severely restricting the application and development of hydraulic systems. In this review paper, the mechanism, harm, and suppression method of pressure pulsation in hydraulic systems are analyzed. Then, the classification and characteristics of pulsation attenuators according to different working principles are described. Furthermore, the critical technology of simulation design, matching method with airborne piston pumps, and preliminary design method of pulsation attenuators are proposed. Finally, the development trend of pulsation attenuators is prospected. This paper provides a reference for the research and application of pressure pulsation attenuators.

Intelligent Manufacturing Technology



(2021)34:21
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Interfacial Bonding Mechanism and Mechanical Performance of Continuous Fiber Reinforced Composites in Additive Manufacturing

Congze Fan• Zhongde Shan• Guisheng Zou• Li Zhan• Dongdong Yan

Abstract: The additive manufacturing of continuous fiber composites has the advantage of a high-precision and efficient forming process, which can realize the lightweight and integrated manufacturing of complex structures. However, many void defects exist between layers in the printing process of additive manufacturing; consequently, the bonding performance between layers is poor. The bonding neck is considered a key parameter for representing the quality of interfacial bonding. In this study, the formation mechanism of the bonding neck was comprehensively analyzed. First, the influence of the nozzle and basement temperatures on the printing performance and bonding neck size was measured. Second, CT scanning was used to realize the quantitative characterization of bonding neck parameters, and the reason behind the deviation of actual measurements from theoretical calculations was analyzed. When the nozzle temperature increased from 180 to 220 °C, CT measurement showed that the bonding neck diameter increased from 0.29 to 0.34 mm, and the cross-sectional porosity reduced from 5.48% to 3.22%. Finally, the fracture mechanism was studied, and the influence of the interfacial bonding quality on the destruction process of the materials was determined. In conclusion, this study can assist in optimizing the process parameters, which improves the precision of the printing parts and performance between the layers.

CONTENTS

Vol. 34, No. 1, February, 2021

(2021)34:9
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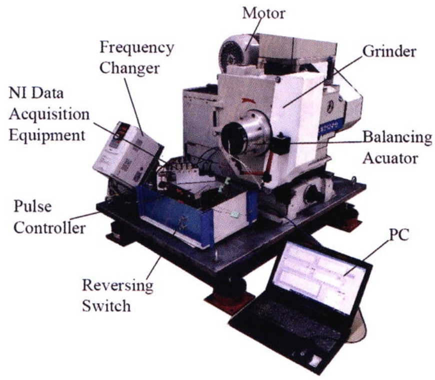
Optimal Design of Novel Electromagnetic-Ring Active Balancing Actuator with Radial Excitation

Xin Pan • Xiaotian He • Haiqi Wu • Chuanlong Ju • Zhinong Jiang • Jinji Gao

Abstract: Imbalance vibration is a typical failure mode of rotational machines and has significant negative effects on the efficiency, accuracy, and service life of equipment. To automatically reduce the imbalance vibration during the operational process, different types of active balancing actuators have been designed and widely applied in actual production. However, the existing electromagnetic-ring active balancing actuator is designed based on an axial excitation structure which can cause structural instability and has low electromagnetic driving efficiency. In this paper, a novel radial excitation structure and the working principle of an electromagnetic-ring active balancing actuator with a combined driving strategy are presented in detail. Then, based on a finite element model, the performance parameters of the actuator are analyzed, and reasonable design parameters are obtained. Self-locking torque measurements and comparative static and dynamic experiments are performed to validate the self-locking torque and driving efficiency of the actuator. The results indicate that this novel active balancing actuator has sufficient self-locking torque, achieves normal step rotation at 2000 r/min, and reduces the driving voltage by 12.5%. The proposed novel balancing actuator using radial excitation and a combination of permanent magnets and soft-iron blocks has improved electromagnetic efficiency and a more stable and compact structure.

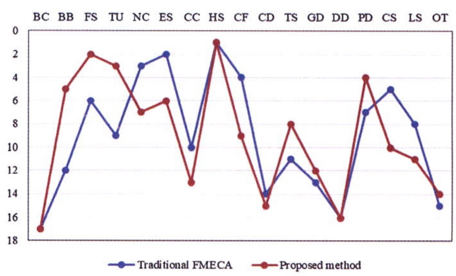


(2021)34:17
DOI: 10.1186/s10033-021-00539-6

Weakness Ranking Method for Subsystems of Heavy-Duty Machine Tools Based on FMECA Information

Zhaojun Yang • Jinyan Guo • Hailong Tian • Chuanhai Chen • Yongfu Zhu • Jia Liu

Abstract: Heavy-duty machine tools are composed of many subsystems with different functions, and their reliability is governed by the reliabilities of these subsystems. It is important to rank the weaknesses of subsystems and identify the weakest subsystem to optimize products and improve their reliabilities. However, traditional ranking methods based on failure mode effect and critical analysis (FMECA) does not consider the complex maintenance of products. Herein, a weakness ranking method for the subsystems of heavy-duty machine tools is proposed based on generalized FMECA information. In this method, eight reliability indexes, including maintainability and maintenance cost, are considered in the generalized FMECA information. Subsequently, the cognition best worst method is used to calculate the weight of each screened index, and the weaknesses of the subsystems are ranked using a technique for order preference by similarity to an ideal solution. Finally, based on the failure data collected from certain domestic heavy-duty horizontal lathes, the weakness ranking result of the subsystems is obtained to verify the effectiveness of the proposed method. An improved weakness ranking method that can comprehensively analyze and identify weak subsystems is proposed herein for designing and improving the reliability of complex electromechanical products.



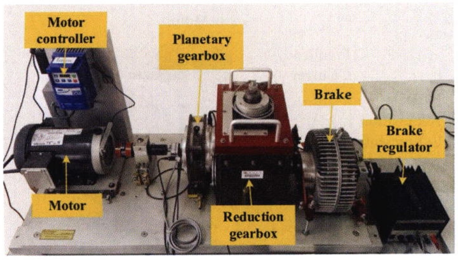
CONTENTS

Vol. 34, No. 1, February, 2021

(2021)34:13
DOI: 10.1186/s10033-020-00520-9

Model Parameter Transfer for Gear Fault Diagnosis under Varying Working Conditions

Chao Chen • Fei Shen • Jiawen Xu • Ruqiang Yan



Abstract: Gear fault diagnosis technologies have received rapid development and been effectively implemented in many engineering applications. However, the various working conditions would degrade the diagnostic performance and make gear fault diagnosis (GFD) more and more challenging. In this paper, a novel model parameter transfer (NMPT) is proposed to boost the performance of GFD under varying working conditions. Based on the previous transfer strategy that controls empirical risk of source domain, this method further integrates the superiorities of multi-task learning with the idea of transfer learning (TL) to acquire transferable knowledge by minimizing the discrepancies of separating hyperplanes between one specific working condition (target domain) and another (source domain), and then transferring both commonality and specialty parameters over tasks to make use of source domain samples to assist target GFD task when sufficient labeled samples from target domain are unavailable. For NMPT implementation, insufficient target domain features and abundant source domain features with supervised information are fed into NMPT model to train a robust classifier for target GFD task. Related experiments prove that NMPT is expected to be a valuable technology to boost practical GFD performance under various working conditions. The proposed methods provides a transfer learning-based framework to handle the problem of insufficient training samples in target task caused by variable operation conditions.

(2021)34:12
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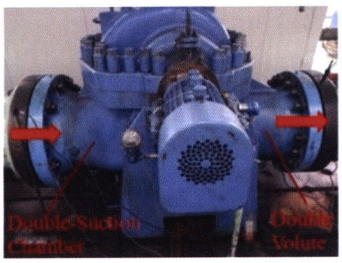
Investigation on Reduction of Pressure Fluctuation for a Double-Suction Centrifugal Pump

Qianqian Li • Shiyang Li • Peng Wu • Bin Huang • Dazhuan Wu



Abstract: Double-suction centrifugal pumps have been applied extensively in many areas, and the significance of pressure fluctuations inside these pumps with large power is becoming increasingly important. In this study, a double-suction centrifugal pump with a high-demand for vibration and noise was redesigned by increasing the flow uniformity at the impeller discharge, implemented by combinations of more than two parameters. First, increasing the number of the impeller blades was intended to enhance the bounding effect that the blades imposed on the fluid. Subsequently, increasing the radial gap between the impeller and volute was applied to reduce the rotor-stator interaction. Finally, the staggered arrangement was optimized to weaken the efficacy of the interference superposition. Based on numerical simulation, the steady and unsteady characteristics of the pump models were calculated. From the fluctuation analysis in the frequency domain, the dimensionless pressure fluctuation amplitude at the blade passing frequency and its harmonics, located on the monitoring points in the redesigned pumps (both with larger radial gap), are reduced a lot. Further, in the volute of the model with new impellers staggered at 12°, the average value for the dimensionless pressure fluctuation amplitude decreases to 6% of that in prototype pump. The dimensionless root-mean-square pressure contour on the mid-span of the impeller tends to be more uniform in the redesigned models (both with larger radial gap); similarly, the pressure contour on the mid-section of the volute presents good uniformity in these models, which in turn demonstrating a reduction in the pressure fluctuation intensity. The results reveal the mechanism of pressure fluctuation reduction in a double-suction centrifugal pump, and the results of this study could provide a reference for pressure fluctuation reduction and vibration performance reinforcement of double-suction centrifugal pumps and other pumps.

CONTENTS

Vol. 34, No. 1, February, 2021

(2021)34:4

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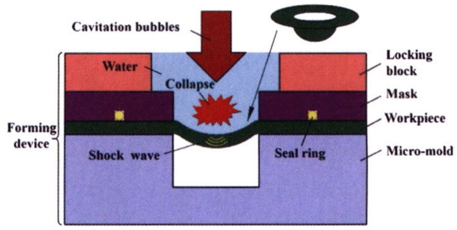
Water-Jet Cavitation Shock Bulging as Novel Microforming Technique

Fuzhu Li • Haiyang Fan • Yuqin Guo • Zhipeng Chen • Xu Wang • Ruitao Li • Hong Liu • Yun Wang

Abstract: With the continuous expansion of the application range of microelectromechanical systems, microdevice forming technology has achieved remarkable results. However, it is challenging to develop new microforming processes that are low cost, environmentally friendly, and highly flexible; the high-energy shock wave in a cavitation bubble's collapse process is used as the loading force. Herein, a new process for the microbulging of the water-jet cavitation is proposed. A series of experiments involving the water-jet cavitation shock microbulging process for TA2 titanium foil is performed on an experimental system. The microforming feasibility of the water-jet cavitation is investigated by characterizing the shape of the formed part. Subsequently, the effects of the main parameters of the water-jet cavitation on the bulging profile, forming depth, surface roughness, and bulging thickness distribution of TA2 titanium foil are revealed. The results show that the plastic deformation increases nonlinearly with the incident pressure. When the incident pressure is 20 MPa, the maximum deformation exceeds 240 μm, and the thickness thinning ratio changes within 10%. The microbulging feasibility of water-jet cavitation is verified by this phenomenon.



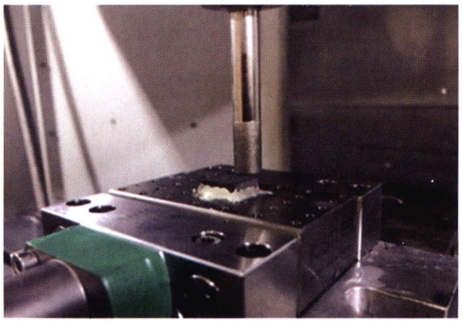
(2021)34:3

DOI: 10.1186/s10033-020-00527-2

Face Grinding Surface Quality of High Volume Fraction SiCp/ Al Composite Materials

Xu Zhao • Yadong Gong • Guiqiang Liang • Ming Cai • Bing Han

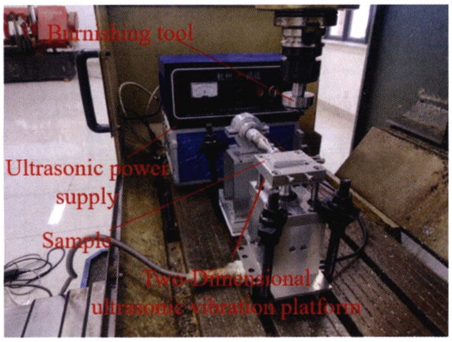
Abstract: The existing research on SiCp/Al composite machining mainly focuses on the machining parameters or surface morphology. However, the surface quality of SiCp/Al composites with a high volume fraction has not been extensively studied. In this study, 32 SiCp/Al specimens with a high volume fraction were prepared and their machining parameters measured. The surface quality of the specimens was then tested and the effect of the grinding parameters on the surface quality was analyzed. The grinding quality of the composite specimens was comprehensively analyzed taking the grinding force, friction coefficient, and roughness parameters as the evaluation standards. The best grinding parameters were obtained by analyzing the surface morphology. The results show that, a higher spindle speed should be chosen to obtain a better surface quality. The final surface quality is related to the friction coefficient, surface roughness, and fragmentation degree as well as the quantity and distribution of the defects. Lower feeding amount, lower grinding depth and appropriately higher spindle speed should be chosen to obtain better surface quality. Lower feeding amount, higher grinding depth and spindle speed should be chosen to balance grind efficiently and surface quality. This study proposes a systematic evaluation method, which can be used to guide the machining of SiCp/Al composites with a high volume fraction.



CONTENTS

Vol. 34, No. 1, February, 2021

(2021)34:19
DOI: 10.1186/s10033-021-00540-z



Investigation of Two-Dimensional Ultrasonic Surface Burnishing Process on 7075-T6 Aluminum

Zhenyu Zhou • Qiuyang Zheng • Cong Ding • Guanglei Yu • Guangjian Peng • Zhongyu Piao

Abstract: A novel two-dimensional ultrasonic surface burnishing process (2D-USBP) is proposed. 7075-T6 aluminum samples are processed by a custom-designed 2D-USBP setup. Parameter optimization of 2D-USBP is conducted to determine the best processing strategy of 7075-T6 aluminum. A uniform design method is utilized to optimize the 2D-USBP process. $U_{13}(13^3)$ and $U_7(7^2)$ tables are established to conduct parameter optimization. Burnishing depth, spindle speed, and feed rate are taken as the control parameters. The surface roughness and Vickers hardness are taken as the evaluation indicators. It establishes the active control models for surface quality. Dry wear tests are conducted to compare the wear-resistance of the 2D-USBP treated sample and the original sample. Results show that the machining quality of 2D-USBP is best under 0.24 mm burnishing depth, 5000 r/min spindle speed, and 25 mm/min feed rate. The surface roughness S_a of the sample is reduced from 2517.758 nm to 50.878 nm, and the hardness of the sample surface is improved from 167 HV to 252 HV. Under the lower load, the wear mechanism of the 2D-USBP treated sample is mainly abrasive wear accompanied by delamination wear, while the wear mechanism of the original sample is mainly delamination wear. Under the higher load, the accumulation of frictional heat on the sample surface transforms the wear mechanisms of the original and the 2D-USBP treated samples into thermal wear.

Mechanism and Robotics

(2021)34:5
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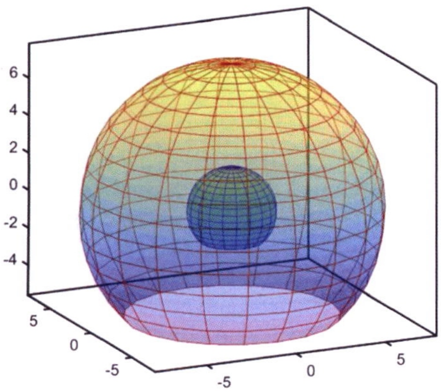


Support and Positioning Mechanism of a Detection Robot inside a Spherical Tank

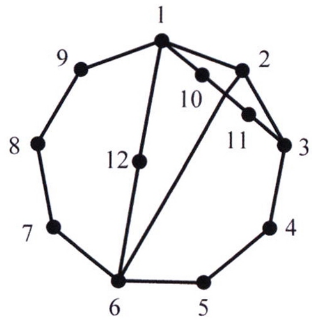
Chunlei Tu • Shanshan Jin • Kai Zheng • Xingsong Wang • Sichong Sun

Abstract: Large pressure equipment needs to be tested regularly to ensure safe operation; wall-climbing robots can carry the necessary tools to inspect spherical tanks, such as cameras and non-destructive testing equipment. However, a wall-climbing robot inside a spherical tank cannot be accurately positioned owing to the particularity of the spherical tank structure. This paper proposes a passive support and positioning mechanism fixed in a spherical tank to improve the adsorption capacity and positioning accuracy of the inspection robot. The main body of the mechanism was designed as a truss composed of carbon fiber telescopic rods and can work in spherical tanks with diameters of 4.6–15.7 m. The structural strength, stiffness, and stability of the mechanism are analyzed via force and deformation simulations. By constructing a mathematical model of the support and positioning mechanism, the influence of structural deformation on the supporting capacity is analyzed and calculated. The robot positioning method based on the support and positioning mechanism can effectively locate the robot inside a spherical tank. Experiments verified the support performance and robot positioning accuracy of the mechanism. This research proposes an auxiliary support and positioning mechanism for a detection robot inside a spherical tank, which can effectively improve the positioning accuracy of the robot and meet the robotic inspection requirements.

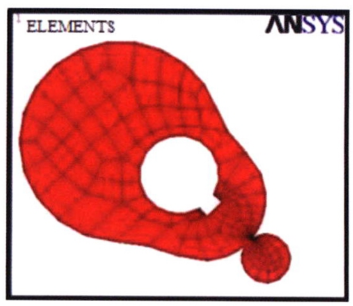
CONTENTS

Vol. 34, No. 1, February, 2021

Abstract: Isomorphism detection is fundamental to the synthesis and innovative design of kinematic chains (KCs). The detection can be performed accurately by using the similarity of KCs. However, there are very few works on isomorphism detection based on the properties of similar vertices. In this paper, an ameliorated multi-order adjacent vertex assignment sequence (AMAVS) method is proposed to seek out similar vertices and identify the isomorphism of the planar KCs. First, the specific definition of AMAVS is described. Through the calculation of the AMAVS, the adjacent vertex value sequence reflecting the uniqueness of the topology features is established. Based on the value sequence, all possible similar vertices, corresponding relations, and isomorphism discrimination can be realized. By checking the topological graph of KCs with a different number of links, the effectiveness and efficiency of the proposed method are verified. Finally, the method is employed to implement the similar vertices and isomorphism detection of all the 9-link 2-DOF(degree of freedom) planar KCs.

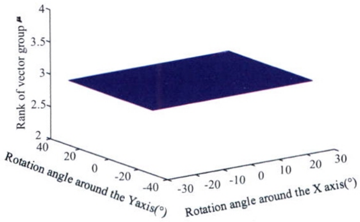


Abstract: The problem of this paper is the high contact stress at the point of contact between the cam and the follower. A pear cam and roller follower mechanism were studied and analyzed for different position of the follower and different contact compression load. The objective of this paper is to study the effect of contact compression load on the contact stress distribution of the cam profile at the point of contact. Four different positions of the follower with the cam was considered (0°, 90°, 180°, and 270°). The theory of circular plate was applied to derive the analytic solution of the contact stress. The numerical simulation had been done using ANSYS Ver. 19.2 package to determine the contact stress, while SolidWorks software was used to investigate follower displacement, velocity, and acceleration. Four distinct values of the compression contact load, such as 3.121 N, 6.242 N, 9.364 N, and 12.485 N, were used in the numerical simulation. In the experiment setup, a photo-elastic technique was carried out in the field of polarized light to exhibit the stress distribution on the cam specimen. The annealed PSM-4 backalate material was used in the experiment setup. The experimental value of contact stress was checked and verified analytically and numerically at the point of contact. The innovation in this paper the use of spring-damper system which reduce the value of contact stress at the point of contact. The contact stress was maximum 2.136 MPa when the follower located at 270° with the cam, while the contact stress was minimum 1.802 MPa when the follower located at 180° at compression load 12.485 N.



CONTENTS

Vol. 34, No. 1, February, 2021



Abstract: The lower-mobility parallel mechanism has been widely used in the engineering field due to its numerous excellent characteristics. However, little work has been devoted to the actuator selection and placement that best satisfy the system's functional requirements during concept design. In this study, a unified approach for synthesizing the actuation spaces of both rigid and flexure parallel mechanisms has been presented, and all possible combinations of inputs could be obtained, laying a theoretical foundation for the subsequent optimization of inputs. According to the linear independence of actuation space and constraint space of the lower-mobility parallel mechanism, a general expression of actuation spaces in the format of screw systems is deduced, a unified synthesis process for the lower-mobility parallel mechanism is derived, and the efficiency of the method is validated with two selective examples based on screw theory. This study presents a theoretical framework for the input selection problems of parallel mechanisms, aiming to help designers select and place actuators in a correct and even optimal way after the configuration design.

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