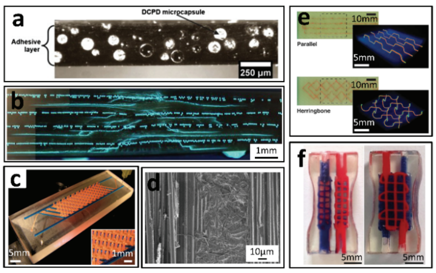
CONTENTS
Vol. 33, June, 2020

CHINESE JOURNAL OF
MECHANICAL ENGINEERING

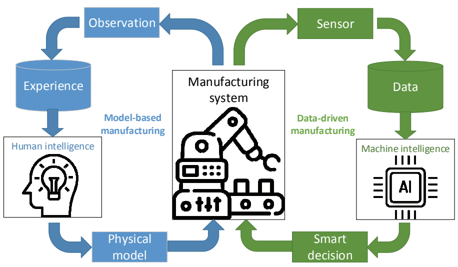
Research Highlight

Review

Abstract: Solid particle erosion is a common phenomenon in engineering fields, such as manufacturing, energy, military and aviation. However, with the rising industrial requirements, the development of anti-solid particle erosion materials remains a great challenge. After billions of years of evolution, several natural materials exhibit unique and exceptional solid particle erosion resistance. These materials achieved the same excellent solid particle erosion resistance performance through diversified strategies. This resistance arises from their micro/nanoscale surface structure and interface material properties, which provide inspiration for novel multiple solutions to solid particle erosion. Here, this review first summarizes the recent significant process in the research of natural anti-solid particle erosion materials and their general design principles. According to these principles, several erosion-resistant structures are available. Combined with advanced micro/nano-manufacturing technologies, several artificial anti-solid particle erosion materials have been obtained. Then, the potential applications of anti-solid particle erosion materials are prospected. Finally, the remaining challenges and promising breakthroughs regarding anti-solid particle erosion materials are briefly discussed.



Abstract: The rapidly increasing demand and complexity of manufacturing process potentiates the usage of manufacturing data with the highest priority to achieve precise analyze and control, rather than using simplified physical models and human expertise. In the era of data-driven manufacturing, the explosion of data amount revolutionized how data is collected and analyzed. This paper overviews the advance of technologies developed for in-process manufacturing data collection and analysis. It can be concluded that groundbreaking sensoring technology to facilitate direct measurement is one important leading trend for advanced data collection, due to the complexity and uncertainty during indirect measurement. On the other hand, physical model-based data analysis contains inevitable simplifications and sometimes ill-posed solutions due to the limited capacity of describing complex manufacturing process. Machine learning, especially deep learning approach has great potential for making better decisions to automate the process when fed with abundant data, while trending data-driven manufacturing approaches succeeded by using limited data to achieve similar or even better decisions. And these trends can be demonstrated by analyzing some typical applications of manufacturing process.



CONTENTS

Vol. 33, June, 2020

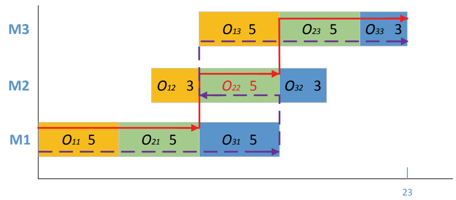
Intelligent Manufacturing Technology

(2020)33:46
DOI: 10.1186/s10033-020-00462-2

Anomalies in Special Permutation Flow Shop Scheduling Problems

Lin Gui • Liang Gao • Xinyu Li

Abstract: Recent researches show that there are some anomalies, which are not satisfied with common sense, appearing in some special permutation flow shop scheduling problems (PFSPs). These anomalies can be divided into three different types, such as changing the processing time of some operations, changing the number of total jobs and changing the number of total machines. This paper summarizes these three types of anomalies showing in the special PFSPs and gives some examples to make them better understood. The extended critical path is proposed and the reason why these anomalies happen in special PFSPs is given: anomalies will occur in these special PFSPs when the time of the operations on the reverse critical path changes. After that, the further reason for these anomalies is presented that when any one of these three types of anomalies happens, the original constraint in the special PFSPs is destroyed, which makes the anomalies appear. Finally, the application of these anomalies in production practice is given through examples and also with the possible research directions. The main contribution of this research is analyzing the intial reason why the anomalies appear in special PFSPs and pointing out the application and the possible research directions of all these three types of anomalies.

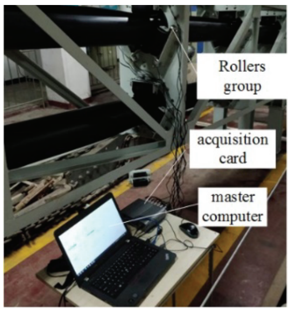


(2020)33:48
DOI: 10.1186/s10033-020-00463-1

Normal Force and Sag Resistance of Pipe Conveyor

Shuaiping Guo • Wei Huang • Xuejun Li

Abstract: Pipe belt conveyor is a new type of environmentally friendly and efficient bulk conveying equipment. In the design of the roller, the belt and the driving motor of pipe belt conveyor, the sag resistance is a key parameter. Meanwhile, the normal force between the conveyor belt and the roller group is the other important factor need be considered and has a great influence on the sag resistance. This paper analyzes a pipe belt conveyor with a diameter of 150 mm to study the calculation method of normal force. And the relationship between the normal force and the sag resistance is explored. Firstly, the normal force is decomposed into three components related to the forming force of belt, material gravity and belt gravity. So it can be expressed as a linear combination of these three quantities, and the coefficients of each component are obtained based on the dynamic analysis of belt-roller. The results show that the coefficient is mainly affected by the material filling rate, and is almost not affected by the distance between the rollers and the density of the material. The calculation method of the normal force is eventually obtained. Secondly, the normal force in the case of different material filling rates is tested by experiments, and the calculation method of the normal force is verified. Thirdly, the variation law of the sag resistance in the case of different roller group spacing and material filling rate is studied by the dynamic model. It is found that the roller group spacing and material filling rate affects the sag resistance by changing the normal force. There is a power function relationship between the sag resistance and the normal force. In the case of different roller group spacing and material filling rate, the relationship among the sag resistance and the normal force remains unchanged. This study results are of great significance to the design of pipe belt conveyor.

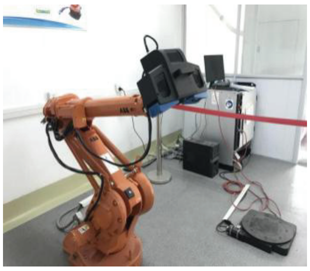


(2020)33:41

DOI: 10.1186/s10033-020-00457-z

Remanufacturing Scheme Design for Used Parts Based on Incomplete Information Reconstruction

Wenhao Huang • Zhigang Jiang • Teng Wang • Yan Wang • Xiaoli Hu



Abstract: The different conditions of use of a component result in a variety of damage levels. Therefore, excluding differences in shape and size, used parts show a high degree of uncertainty regarding failure characteristics, quality conditions, and remaining life, which seriously affects the efficiency of a remanufacturing scheme design. Aiming to address this problem, a remanufacturing scheme design method based on the reconstruction of incomplete information of used parts is proposed. First, the remaining life of the reconstructed model is predicted by finite element analysis, and the demand for the next life cycle is determined. Second, the scanned 3D damage point cloud data are registered with the original point cloud data using the integral iterative method to construct a missing point cloud model to achieve the restoration of geometric information. Then, according to reverse engineering and laser cladding remanufacturing, the tool remanufacturing process path can be generated by the tool contact point path section line method. Finally, the proposed method is adopted for turbine blades to evaluate the effectiveness and feasibility of the proposed scheme. This study proposes a remanufacturing scheme design method based on the incomplete reconstruction of used part information to solve the uncertain and highly personalized problems in remanufacturing.

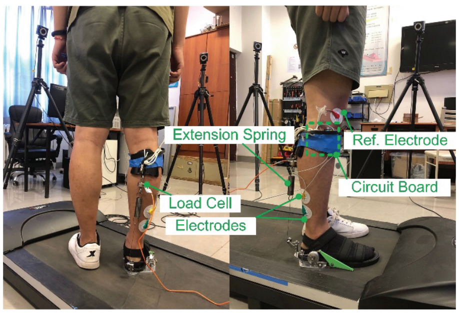
Mechanism and Robotics

(2020)33:49

DOI: 10.1186/s10033-020-00465-z

Design of a Passive Gait-based Ankle-foot Exoskeleton with Self-adaptive Capability

Xiangyang Wang • Sheng Guo • Bojian Qu • Majun Song • Haibo Qu



Abstract: Propulsion during push-off is the key to realizing human locomotion. Humans have evolved a way of walking with high energy utilization, but it can be further improved. Drawing inspiration from the muscle-tendon unit, a passive spring-actuated ankle-foot exoskeleton is designed to assist with human walking and to lengthen walking duration by mechanically enhancing walking efficiency. Detection of the gait events is realized using a smart clutch, which is designed to detect the contact states between the shoe sole and the ground, and automatically switch its working state. The engagement of a suspended spring behind the human calf muscles is hence controlled and is in synchrony with gait. The device is completely passive and contains no external power source. Energy is stored and returned passively using the clutch. In our walking trials, the soleus electromyography activity is reduced by as much as 72.2% when the proposed ankle-foot exoskeleton is worn on the human body. The influence of the exoskeleton on walking habits is also studied. The results show the potential use of the exoskeleton in humans' daily life.

CONTENTS

Vol. 33, June, 2020

(2020)33:50
DOI: 10.1186/s10033-020-00466-y

Configuration Synthesis and Performance Analysis of 9-Speed Automatic Transmissions

Huafeng Ding • Changwang Cai • Ziming Chen • Tao Ke • Bowen Mao

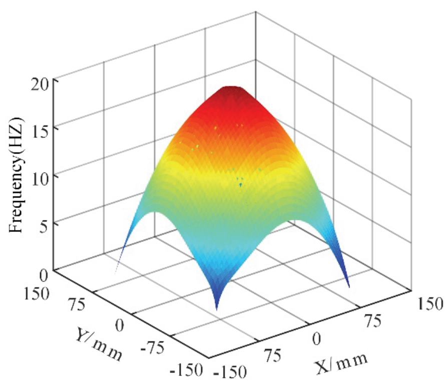
Abstract: Current research of automatic transmission (AT) mainly focus on the improvement of driving performance, and configuration innovation is one of the main research directions. However, finding new configurations of ATs is one of the main limitations of configuration innovation. In the present study, epicyclic gear trains (EGTs) are applied to investigate mechanisms of 9-speed ATs. Then four kinematic configurations are proposed for automatic transitions. In order to evaluate the performance of proposed mechanisms, the lever analogy method is applied to conduct kinematic and mechanical analyses. The power flow analysis is conducted, and then transmission efficiencies are calculated based on the torque method. The comparative analysis between the proposed and existing mechanisms is carried out where obtained results show that proposed mechanisms have reasonable performance and can be used in ATs. The prototype of an AT is manufactured and the speed test is conducted, which proves the accuracy of analysis and the feasibility of proposed mechanisms.

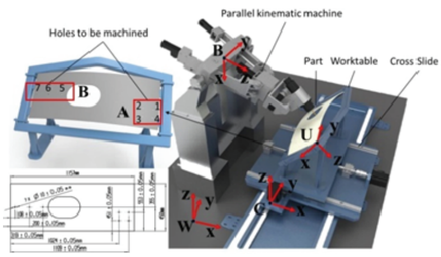
(2020)33:44
DOI: 10.1186/s10033-020-00460-4

Dynamic Modeling and Analysis of 5–PSS/UPU Parallel Mechanism with Elastically Active Branched Chains

Yanbiao Li • Hang Zheng • Bo Chen • Peng Sun • Zesheng Wang • Kun Shuai • Yi Yue

Abstract: To study the characteristics of the 5–prismatic–spherical–spherical (PSS)/universal–prismatic–universal (UPU) parallel mechanism with elastically active branched chains, the dynamics modeling and solutions of the parallel mechanism were investigated. First, the active branched chains and screw sliders were considered as spatial beam elements and plane beam element models, respectively, and the dynamic equations of each element model were derived using the Lagrange method. Second, the equations of the 5–PSS/UPU parallel mechanism were obtained according to the kinematic coupling relationship between the active branched chains and moving platform. Finally, based on the parallel mechanism dynamic equations, the natural frequency distribution of the 5–PSS/UPU parallel mechanism in the working space and elastic displacement of the moving platform were obtained. The results show that the natural frequency of the 5–PSS/UPU parallel mechanism under a given motion situation is greater than its operating frequency. The maximum position error is –0.096 mm in direction *Y*, and the maximum orientation error is –0.29° around the *X*-axis. The study provides important information for analyzing the dynamic performance, dynamic optimization design, and dynamic control of the 5–PSS/UPU parallel mechanism with elastically active branched chains.





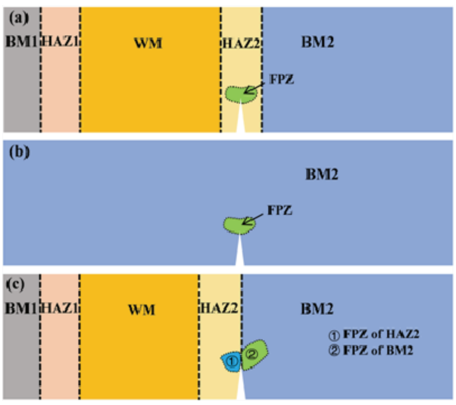
(2020)33:40
DOI: 10.1186/s10033-020-00451-5

Improved Stiffness Modeling for An Exechon-Like Parallel Kinematic Machine (PKM) and Its Application

Nanyan Shen • Liang Geng • Jing Li • Fei Ye • Zhuang Yu • Zirui Wang

Abstract: Hole drilling or contour milling for the large and complex workpieces such as automobile panels and aircraft fuselages makes a high combined demand on machining accuracy, stiffness and workspace of machining equipment. Therefore, a 5-DOF (degrees of freedom) parallel kinematic machine (PKM) with redundant constraints is proposed. Based on the kinematics analysis of the parallel mechanism using intermediate variables, the kinematics problems of the PKM are solved through equivalent kinematics model. The structural stiffness matrix method is adopted to model the stiffness of the parallel mechanism of the PKM, where the stiffness of each joint and branch component is obtained by stiffness formula and finite element analysis. And the stiffness model of the parallel mechanism is improved by correction coefficient matrix, each element of which is constructed as a polynomial function of three independent end variables of the parallel mechanism. The terminal stiffness matrices obtained by simulation result are used to determine the coefficients of polynomial function by least square fitting to describe the correction coefficient over the workspace of the parallel mechanism quantitatively. The experiment results prove that the modification method can greatly improve the stiffness model of the parallel mechanism. To enhance the machining accuracy of the PKM, the proposed kinematics model and the improved stiffness model are utilized to optimize the working stiffness of parallel machine by searching the best relative position of parallel machine and workpiece. A plate workpiece taken as example is examined in the case study section, which demonstrates the effectiveness of optimization method.

Smart Materials



(2020)33:27
DOI: 10.1186/s10033-020-00444-4

Numerical Investigation on Fracture Initiation Properties of Interface Crack in Dissimilar Steel Welded Joints

Longfei Zhao • Chendong Shao • Yasuhito Takashima • Fumiyoshi Minami • Fenggui Lu

Abstract: Fracture toughness property is of significant importance when evaluating structural safety. The current research of fracture toughness mainly focused on crack in homogeneous material and experimental results. When the crack is located in a welded joint with high-gradient microstructure and mechanical property distribution, it becomes difficult to evaluate the fracture toughness behavior since the stress distribution may be affected by various factors. In recent years, numerical method has become an ideal approach to reveal the essence and mechanism of fracture toughness behavior. This study focuses on the crack initiation behavior and driving force at different interfaces in dissimilar steel welded joints. The stress and strain fields around the crack tip lying at the interfaces of ductile-ductile, ductile-brittle and brittle-brittle materials are analyzed by the numerical simulation. For the interface of ductile-ductile materials, the strain concentration on the softer material side is responsible for ductile fracture initiation. For the ductile-brittle interface, the shielding effect of the ductile material plays an important role in decreasing the fracture driving force on the brittle material side. In the case of brittle-brittle interface, a careful matching is required, because the strength mismatch decreases the fracture driving force in one side, whereas the driving force in another side is increased. The results are deemed to offer support for the safety assessment of welded structures.

CONTENTS

Vol. 33, June, 2020

(2020)33:39
DOI: 10.1186/s10033-020-00456-0

Residual Stress Relaxation of Thin-walled Long Stringer Made of Aluminum Alloy 7050-T7451 under Transportation Vibration

Yinfei Yang • Lu Jin • Jixing Du • Liang Li • Wei Yang

Abstract: Thin-walled long stringer made of aluminum alloy 7050-T7451 is prone to deformation during transportation, so a research of residual stress relaxation was launched in this paper. The transport resonance stress of long stringer was analyzed based on the power spectral density of road transport acceleration. The residual stress relaxation experiment of aluminum alloy 7050-T7451 under different equivalent stress levels was designed and carried out. According to the amount of residual stress relaxation in the experiment, an analytical model was established with the equivalent stress level coefficient. The deflection range of long stringer was evaluated under different damping ratios. The results show that when the equivalent stress exceeds $0.8\sigma_{0.2}$, the residual stress relaxation of the thin-walled samples occurs. The residual stress relaxation increases linearly with the equivalent stress, which is logarithmically related to the loading cycle. The deformation caused by residual stress relaxation of the long stringer is proportional to the square of the length and the bending moment caused by stress rebalance, and inversely proportional to the moment of inertia of the structure. As the damping ratio decreases from 0.03 to 0.01, the total deflection of the long stringer increases from 0 to above 1.55 mm.

(2020)33:45
DOI: 10.1186/s10033-020-00461-3

Integrated Modelling of Microstructure Evolution and Mechanical Properties Prediction for Q&P Hot Stamping Process of Ultra-High Strength Steel

Yang Chen • Huizhen Zhang • Johnston Jackie Tang • Xianhong Han • Zhenshan Cui

Abstract: High strength steel products with good ductility can be produced via Q&P hot stamping process, while the phase transformation of the process is more complicated than common hot stamping since two-step quenching and one-step carbon partitioning processes are involved. In this study, an integrated model of microstructure evolution relating to Q&P hot stamping was presented with a persuasively predicted results of mechanical properties. The transformation of diffusional phase and non-diffusional phase, including original austenite grain size individually, were considered, as well as the carbon partitioning process which affects the secondary martensite transformation temperature and the subsequent phase transformations. Afterwards, the mechanical properties including hardness, strength, and elongation were calculated through a series of theoretical and empirical models in accordance with phase contents. Especially, a modified elongation prediction model was generated ultimately with higher accuracy than the existed Mileiko's model. In the end, the unified model was applied to simulate the Q&P hot stamping process of a U-cup part based on the finite element software LS-DYNA, where the calculated outputs were coincident with the measured consequences.