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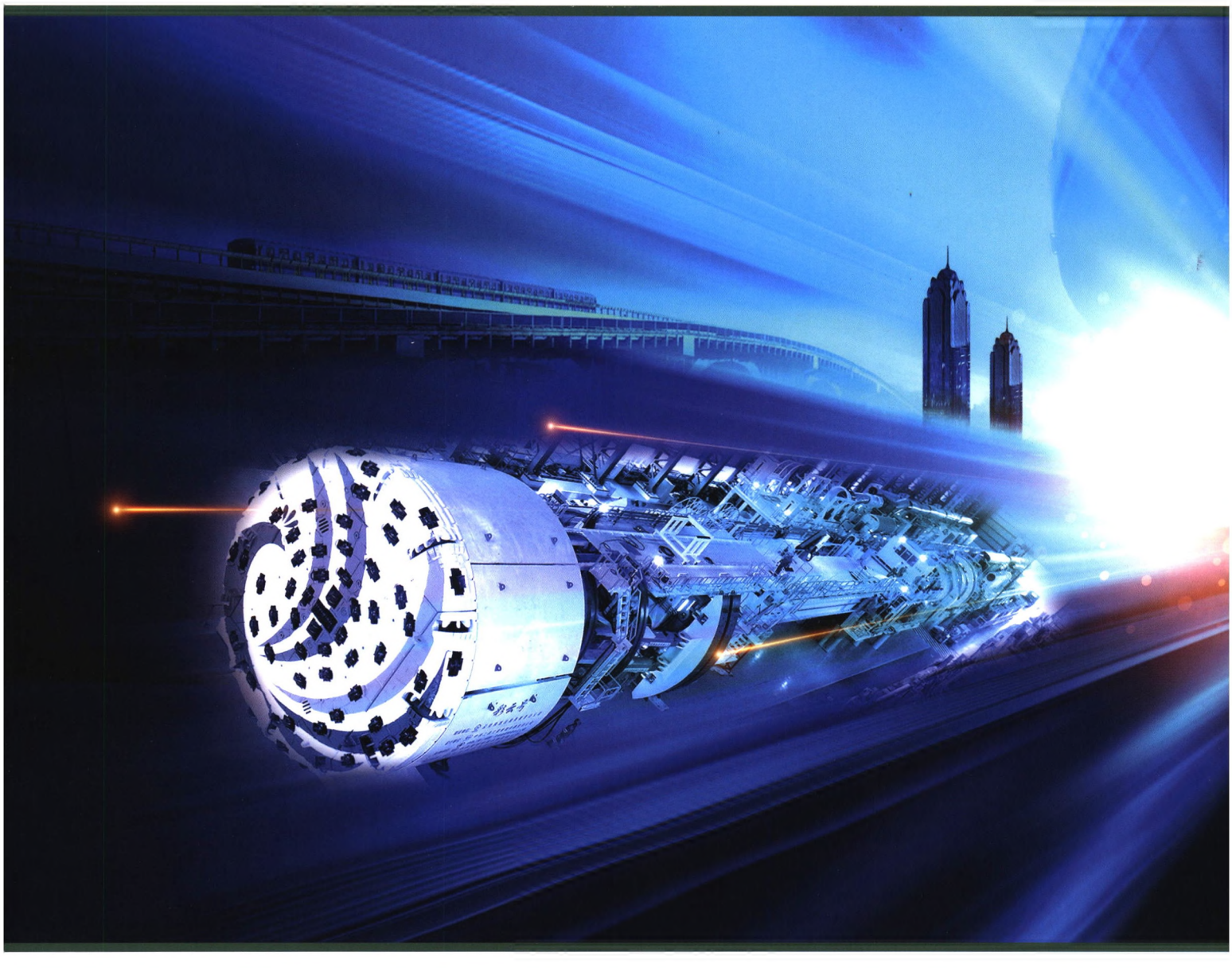

DOI: 10.1186/s10033-019-0414-y

Nonlinear Static and Dynamic Stiffness Characteristics of Support Hydraulic System of TBM

Jianfeng Tao, Junbo Lei, Chengliang Liu and Wei Yuan

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CONTENTS

Vol. 32, December, 2019

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REVIEW

(2019)32:93
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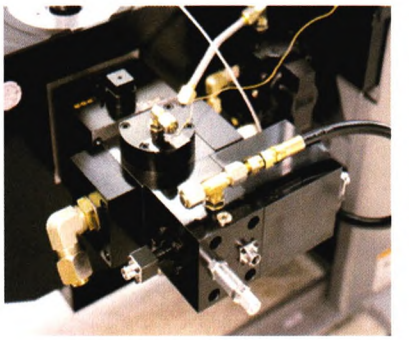
Present Status and Prospect of High-Frequency Electro-hydraulic Vibration Control Technology. Yi Liu • Tao Wang • Guofang Gong • Rujun Gao

Abstract: Electro-hydraulic vibration equipment (EHVE) is widely used in vibration environment simulation tests, such as vehicles, weapons, ships, aerospace, nuclear industries and seismic waves replication, etc., due to its large output power, displacement and thrust, as well as good workload adaptation and multi-controllable parameters. Based on the domestic and overseas development of high-frequency EHVE, dividing them into servo-valve controlled vibration equipment and rotary-valve controlled vibration equipment. The research status and progress of high-frequency electro-hydraulic vibration control technology (EHVCT) are discussed, from the perspective of vibration waveform control and vibration controller. The problems of current electro-hydraulic vibration system bandwidth and waveform distortion control, stability control, offset control and complex vibration waveform generation in high-frequency vibration conditions are pointed out. Combining the existing rotary-valve controlled high-frequency electro-hydraulic vibration method, a new twin-valve independently controlled high-frequency electro-hydraulic vibration method is proposed to break through the limitations of current electro-hydraulic vibration technology in terms of system frequency bandwidth and waveform distortion. The new method can realize independent adjustment and control of vibration waveform frequency, amplitude and offset under high-frequency vibration conditions, and provide a new idea for accurate simulation of high-frequency vibration waveform.

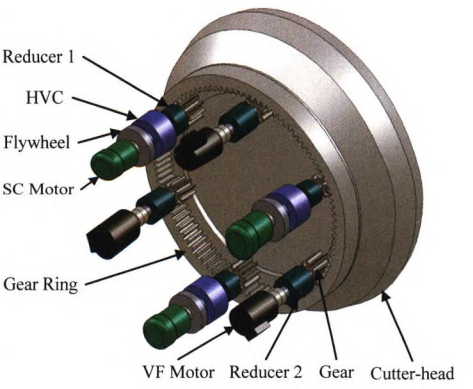


Tunnel Boring Machine Equipment

(2019)32:102
DOI: 10.1186/s10033-019-0413-z

A Numerical Method for Extrication Characteristics of TBM Cutter-Head with the HVC. Huasheng Gong • Haibo Xie • Huayong Yang

Abstract: Achieving highly efficient extrication of the tunnel boring machine (TBM) cutter-head driving system from the collapsed surrounding rock has become a key problem globally, and significant effort has been directed to improve TBM cutter-head extricating ability. In this study, the characteristics of a hydro-viscous device have been investigated to improve extricating performance of the TBM cutter-head. A numerical method based on an explicit pressure-linked equation is presented for computing the film parameters of the HVC, which is then applied to investigate extrication characteristics of a TBM cutter-head with a hydro-viscous clutch (HVC). The explicit pressure-linked equation is derived from the Navier-Stokes equations and the conservation equation, where boundary conditions are involved. The model of a cutter-head driving system with an HVC is established, and the extrication characteristics of the cutter-head driving system are analyzed and compared with three extrication strategies. The variation in extrication torque shows that the linear strategy or positive parabolic strategy are preferred for their relatively high extrication efficiency and low rigid impact, and the effects of throughflow rate on torque transmission are also investigated. The test rig of the TBM cutter-head driving system was set up to validate the numerical method and the model of a cutter-head driving system, and the feasibility of the proposed numerical method for researching the extrication of the TBM cutter-head is verified.



CONTENTS

Vol. 32, December, 2019

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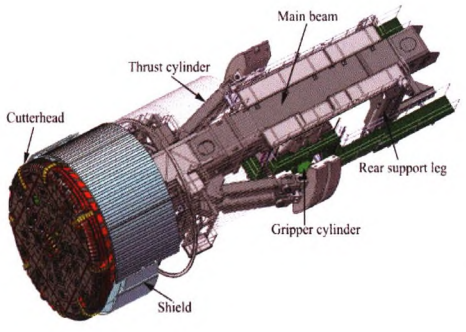
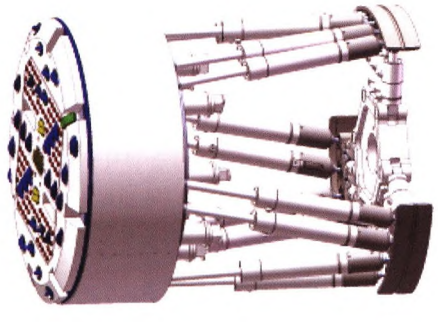
Nonlinear Static and Dynamic Stiffness Characteristics of Support Hydraulic System of TBM. Jianfeng Tao • Junbo Lei • Chengliang Liu • Wei Yuan



Abstract: Full-face hard rock tunnel boring machines (TBM) are essential equipment in highway and railway tunnel engineering construction. During the tunneling process, TBM have serious vibrations, which can damage some of its key components. The support system，an important part of TBM, is one path through which vibrational energy from the cutter head is transmitted. To reduce the vibration of support systems of TBM during the excavation process, based on the structural features of the support hydraulic system, a nonlinear dynamical model of support hydraulic systems of TBM is established. The influences of the component structure parameters and operating conditions parameters on the stiffness characteristics of the support hydraulic system are analyzed. The analysis results indicate that the static stiffness of the support hydraulic system consists of an increase stage, stable stage and decrease stage. The static stiffness value increases with an increase in the clearances. The pre-compression length of the spring in the relief valve affects the range of the stable stage of the static stiffness, and it does not affect the static stiffness value. The dynamic stiffness of the support hydraulic system consists of a U-shape and reverse U-shape. The bottom value of the U-shape increases with the amplitude and frequency of the external force acting on the cylinder body, however, the top value of the reverse U-shape remains constant. This study instructs how to design the support hydraulic system of TBM.

(2019)32:107
DOI: 10.1186/s10033-019-0416-9

Research on the Structural Rigidity Characteristics of a Reconfigurable TBM Thrust Mechanism. Younan Xu • Xinjun Liu • Jiyu Xu



Abstract: To improve the adaptability of TBMs in diverse geological environments, this paper proposes a reconfigurable Type-V thrust mechanism (V-TM) with rearrangeable working states, in which structural stiffness can be automatically altered during operation. Therefore, millions of configurations can be obtained, and thousands of instances of working status per configuration can be set respectively. Nonetheless, the complexity of configurations and diversity of working states contributes to further complications for the structural stiffness algorithm. This results in challenges such as difficulty calculating the payload compliance index and the environment adaptability index. To solve this problem, we use the configuration matrix to describe the relationship between propelling jacks under reconfiguration and adopt pattern vectors to describe the working state of each hydraulic cylinder. Then, both the dynamic compatible equation between propeller forces of the hydraulic cylinders and driving forces, and the kinematic harmonizing equation between the hydraulic cylinder displacements and their deformations are established. Next, we derive the stiffness analytical equation using Hooke's law and the Jacobian Matrix. The proposed approach provides an effective algorithm to support structural rigidity analysis, and lays a solid theoretical foundation for calculating the performance indexes of the V-TM. We then analyze the rigidity characteristics of typical configurations under different working states, and obtain the main factors affecting structural stiffness of the V-TM. The results show the deviation degree of structural parameters in hydraulic cylinders within the same group, and the working status of propelling jacks. Finally, our constructive conclusions contribute valuable information for matching and optimization by drawing on the factors that affect the structural rigidity of the V-TM.

CONTENTS

Vol. 32, December, 2019

(2019)32:98
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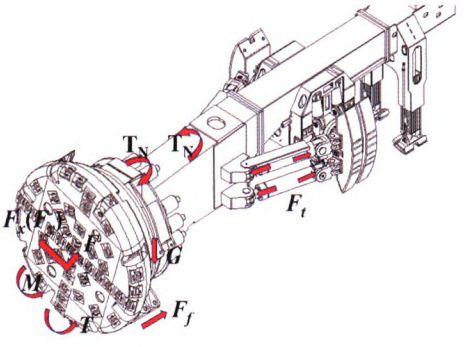
Dynamic Characteristics Analysis with Multi-Directional Coupling in a TBM Mainframe.

Laikuang Lin • Yimin Xia • Zhengguang Li • Caizhang Wu • Yongliang Cheng • Qing Tan

Abstract: The cutterhead of a full-face rock tunnel boring machine (TBM) is constantly subjected to varying impact and dynamic loads during tunneling processes, resulting in relatively large vibrations that could easily lead to fatigue cracking of the entire machine and affect the tunneling performance and efficiency. To explore the dynamic characteristics of the TBM mainframe, a TBM from a water-diversion project is investigated in this research. According to the TBM vibration transmission route, an equivalent dynamic model of the TBM mainframe is established using the lumped-mass method in which the relevant dynamic parameters are solved. Additionally, the dynamic response characteristics of the TBM mainframe are analyzed. The results indicate that the vibration levels in three directions are approximately the same, the multi-directional vibration of the cutterhead is more intense than that of other components, and the vibration and external excitation exhibit identical change trends. A set of vibration field tests is performed to analyze the in situ dynamic responses of the mainframe and verify the correctness of the dynamic model. The theoretical and measured acceleration values of the TBM mainframe have the same magnitude, which proves the validity of the dynamic model and its solution. The aforementioned results provide an important theoretical value and practical significance for the design and assessment of the TBM mainframe.

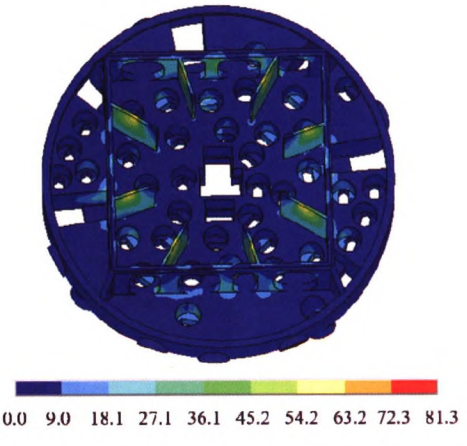


(2019)32:99
DOI: 10.1186/s10033-019-0411-1

On the Loads for Strength Design of Cutterhead of Full Face Rock Tunnel Boring Machine.

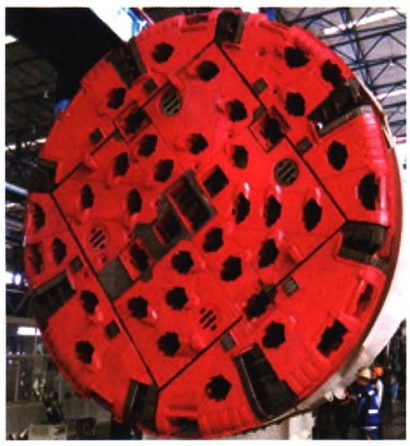
Meidong Han • Zongxi Cai • Chuanyong Qu

Abstract: Cutterhead loads are the key mechanical parameters for the strength design of the full face hard rock tunnel boring machine (TBM). Due to the brittle rock-breaking mechanism, the excavation loads acting on cutters fluctuate strongly and show some randomness. The conventional method that using combinations of some special static loads to perform the strength design of TBM cutterhead may lead to strength failure during working practice. In this paper, a three-dimensional finite element model for coupled cutterhead-rock is developed to determine the cutterhead loads. Then the distribution characteristics and the influence factors of cutterhead loads are analyzed based on the numerical results. It is found that, as time changes, the normal and tangential forces acting on cutters and the total torque acting on the cutterhead approximately distribute log normally, while the total thrusts acting on the cutterhead approximately show a normal distribution. Furthermore, the statistical average values of cutterhead loads are proportional to the uniaxial compressive strength (UCS) of cutting rocks. The values also change with the penetration and the diameter of cutterhead following a power function. Based on these findings, we propose a three-parameter model for the mean of cutterhead loads and a method of generating the random cutter forces. Then the strength properties of a typical cutterhead are analyzed in detail using loads generated by the new method. The optimized cutterhead has been successfully applied in engineering. The method in this paper may provide a useful reference for the strength design of TBM cutterhead.



CONTENTS

Vol. 32, December, 2019

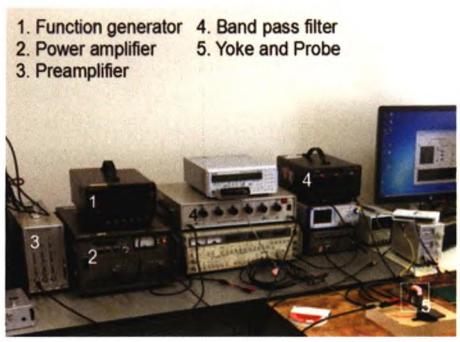


(2019)32:103
DOI: 10.1186/s10033-019-0410-2

A New System to Evaluate Comprehensive Performance of Hard-Rock Tunnel Boring Machine Cutterheads. Ye Zhu • Wei Sun • Junzhou Huo • Zhichao Meng

Abstract: The accurate performance evaluation of a cutterhead is essential to improving cutterhead structure design and predicting project cost. Through extensive research, this paper evaluates the performance of a tunnel boring machine (TBM) cutterhead for cutting ability and slagging ability. This paper propose cutting efficiency, stability, and continuity of slagging as the evaluation indexes of comprehensive cutterhead performance. On the basis of research of true TBM engineering applications, this paper proposes a calculation method for each index. A slagging efficiency index with a ratio of the maximum difference between the slagging amount and average slagging is established. And a slagging stability index with a ratio of the maximum slagging fluctuation and average slagging is presented. Meanwhile, a cutting efficiency index by the weighed average value of multistage rock fragmentation of a cutter's specific energy is established. The Robbins and China Railway Construction Corporation (CRCC) cutterheads are evaluated. The results show that under the same thrust and torque, the slagging stability of the CRCC scheme is worse, but the slagging continuity of the CRCC scheme is better. The cutting ability index shows that the CRCC cutterhead is more efficient.

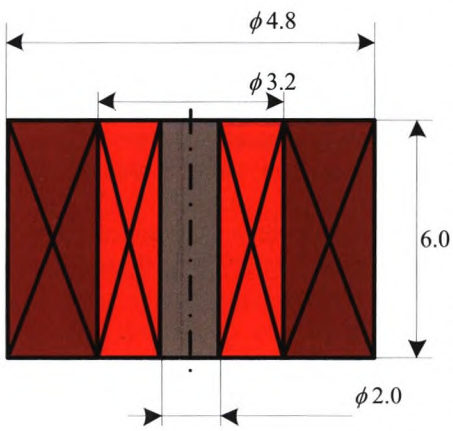
Nondestructive Testing and Evaluation



(2019)32:104
DOI: 10.1186/s10033-019-0420-0

Caution to Apply Magnetic Barkhausen Noise Method to Nondestructive Evaluation of Plastic Deformation in Some Ferromagnetic Materials. Manru He • Takanori Matsumoto • Tetsuya Uchimoto • Toshiyuki Takagi • Hongen Chen • Shejuan Xie • Zhenmao Chen

Abstract: Magnetic Barkhousen Noise (MBN) method is known as an effective nondestructive evaluation (NDE) method for evaluation of residual stress in ferromagnetic materials. Some studies on the feasibility of the MBN method for NDE of residual strains were also conducted and found applicable. However, these studies are mainly focused on the state of residual strains which were introduced through a one-cycle-loading process. In practice, however, structures may suffer from an unpredictable and complicated loading history, i.e., the final state of plastic strain may be induced by several times of large loads. Whether the loading history has influences on MBN signals or not is of great importance for the practical application of the MBN method. In this paper, several ferromagnetic specimens with the same final state of residual strain but of different loading history were fabricated and inspected by using a MBN testing system. The experimental results reveal that the loading history has a significant influence on the detected MBN signals especially for a residual strain in range less than 1%, which doubts the feasibility to apply the MBN method simply in the practical environment. In addition, micro-observations on the magnetic domain structures of the plastic damaged specimens were also carried out to clarify the influence mechanism of loading history on the MBN signals.



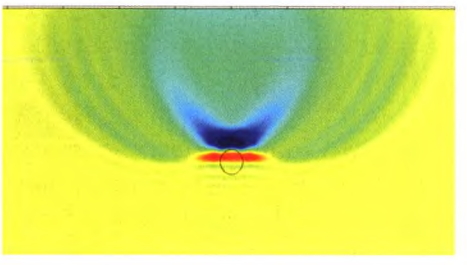
(2019)32:106
DOI: 10.1186/s10033-019-0419-6

Characteristics of Eddy Current Attenuation and Thickness Measurement of Metallic Plate. Zhiwei Zeng • Pengcheng Ding • Jiayi Li • Shaoni Jiao • Junming Lin • Yonghong Dai

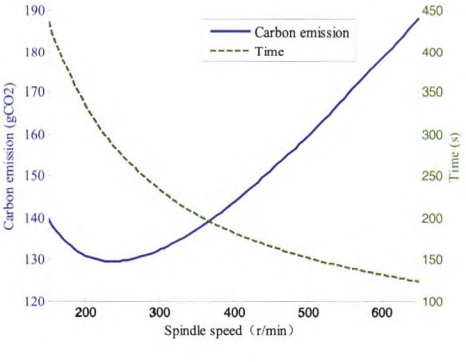
Abstract: In eddy current testing, the law of attenuation of eddy current (EC) is of great concern. In conductive half space under the excitation of uniform magnetic field, the EC density decreases exponentially in the depth direction. However, in conductor with finite thickness tested by coil, the distribution of EC in the depth direction is more complicated. This paper studies the characteristics of EC attenuation in metallic plate of finite thickness. Simulation results show that there is an EC reflection at the bottom of plate, which changes the law of EC attenuation. A new concept, namely the equivalent attenuation coefficient, is proposed to quantify the speed of EC attenuation. The characteristics of EC attenuation are utilized to explain the nonmonotonic relation between coil voltage and plate thickness. Procedure of selecting frequency is discussed. Thereafter, measurement of plate thickness is carried out and accurate result is obtained.

CONTENTS

Vol. 32, December, 2019



Intelligent Manufacturing Technology



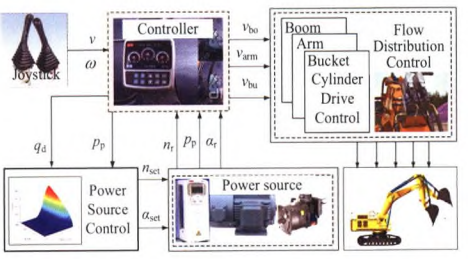
CONTENTS

Vol. 32, December, 2019

(2019)32:100
DOI: 10.1186/s10033-019-0415-x

Power Matching and Energy Efficiency Improvement of Hydraulic Excavator Driven with Speed and Displacement Variable Power Source.

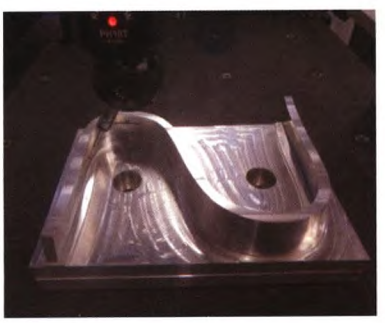
Lei Ge • Long Quan • Xiaogang Zhang • Zhixin Dong • Jing Yang



Abstract: Mobile machinery energy efficiency and emission pollution are the national and worldwide issues. This paper contributes in solving these problems by applying a speed variable power source. Unfortunately, almost all of the speed variable systems have the dynamic response problem when the motor starts with full load or heavy load. To address this problem, a hydraulic accumulator is used to balance the load of the power source for assisting starting of the motor and a matching method combined with speed and displacement control of the pump is proposed to improve the energy efficiency and dynamic performance simultaneously under different working conditions. Also, the power source/ valve combined control strategy of an independent metering system is designed to realize flow matching of the whole system. Firstly, a test system is established to study the dynamic performance and energy efficiency of the speed variable power source with an auxiliary accumulator. Working performance and energy consumption of the power source under different rotating speeds and different loads are studied. And then, the hydraulic excavator test rig with the proposed system is constructed. Furthermore, the working performance of the excavator with the speed-fixed and speed-variable strategy are studied comparatively. Results show that, compared with fixed-speed strategy, the electric power consumption during the idle period and partial load condition can be reduced about 2.05 kW and 1.37 kW. The energy efficiency of speed variable power source is about 40%–71%, which is higher than that of the fixed-speed power source by 3%–10%.

(2019)32:90
DOI: 10.1186/s10033-019-0404-0

An Improved Measurement Uncertainty Calculation Method of Profile Error for Sculptured Surfaces. Chenhui Liu • Zhanjie Song • Yicun Sang • Gaiyun He



Abstract: The current researches mainly adopt "Guide to the expression of uncertainty in measurement (GUM)" to calculate the profile error. However, GUM can only be applied in the linear models. The standard GUM is not appropriate to calculate the uncertainty of profile error because the mathematical model of profile error is strongly non-linear. An improved second-order GUM method (GUMM) is proposed to calculate the uncertainty. At the same time, the uncertainties in different coordinate axes directions are calculated as the measuring points uncertainties. In addition, the correlations between variables could not be ignored while calculating the uncertainty. A k-factor conversion method is proposed to calculate the converge factor due to the unknown and asymmetrical distribution of the output quantity. Subsequently, the adaptive Monte Carlo method (AMCM) is used to evaluate whether the second-order GUMM is better. Two practical examples are listed and the conclusion is drawn by comparing and discussing the second-order GUMM and AMCM. The results show that the difference between the improved second-order GUM and the AMCM is smaller than the difference between the standard GUM and the AMCM. The improved second-order GUMM is more precise in consideration of the nonlinear mathematical model of profile error.

(2019)32:91
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Surface Texture Analysis after Hydrostatic Burnishing on X38CrMoV5-1 Steel. Slawomir Swirad

Abstract: Ball burnishing is a plastic deformation process used as a surface smoothing and surface improvement finishing treatment after turning or milling processes. This process changes the surface stereometrics of the previously machining surface. Burnishing with hydrostatic tools can be easily and effectively used on both conventional and Computer Numeric Control (CNC) machines. The existing research of the burnishing process mainly focuses on the functional surface characterization, for example, surface roughness, wear resistance, surface layer hardness, etc. There is a lack of references reporting a detailed analysis of 3D parameters calculation with a mathematical model to evaluate the results of the ball burnishing. This paper presents the effect of ball burnishing process parameters with hydrostatic tools on the resulting surface structure geometry. The surface topography parameters were calculated using the TalyMap software. Studies were conducted based on Hartley's static, determined plan. Such a plan can be built on a hypersphere or hypercube. In this work, a hypercube was used. In the case of Hartley's plan makes it possible to define the regression equation in the form of a polynomial of the second degree. The input process parameters considered in this study include the burnishing rate, applied pressure, and line-to-line pitch. The significant influence of these parameters was confirmed and described as a mathematical power model. The results also showed a positive effect of hydrostatic burnishing on the roughness and geometric structure of the surface.

CONTENTS

Vol. 32, December, 2019

Smart Materials

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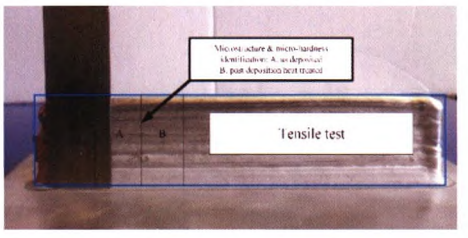
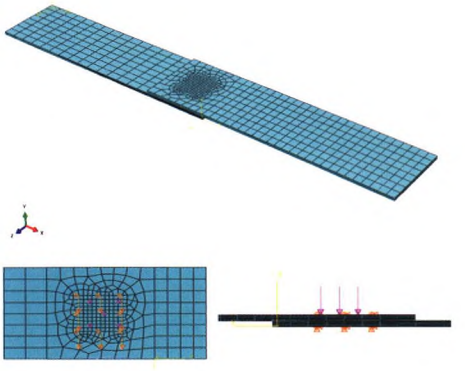
Microstructure and Mechanical Properties of Wire + Arc Additively Manufactured 2050 Al-Li Alloy Wall Deposits. Hao Zhong • Bojin Qi • Baoqiang Cong • Zewu Qi • Hongye Sun



Abstract: Aluminum-Lithium (Al-Li) alloy is a topic of great interest owing to its high strength and light weight, but there are only a few applications of Al-Li alloy in wire + arc additive manufacturing (WAAM) process. To identify its feasibility in WAAM process, a special AA2050 Al-Li alloy wire was produced and employed in the production of straight-walled components, using a WAAM system based on variable polarity gas tungsten arc welding (VP-GTAW) process. The influence of post-deposited heat treatment on the microstructure and property of the deposit was investigated using optical micrographs (OM), scanning electron microscopy (SEM), X-ray diffraction (XRD), hardness and tensile properties tests. Results revealed that the microstructures of AA2050 aluminum deposits varied with their location layers. The upper layers consisted of fine equiaxed grains, while the bottom layer exhibited a coarse columnar structure. Mechanical properties witnessed a significant improvement after post-deposited heat treatment, with the average micro-hardness reaching 141HV and the ultimate tensile strength exceeding 400 MPa. Fracture morphology exhibited a typical ductile fracture.

(2019)32:97
DOI: 10.1186/s10033-019-0409-8

Ultrasonic Welding of Magnesium-Titanium Dissimilar Metals: A Study on Thermo-mechanical Analyses of Welding Process by Experimentation and Finite Element Method. Dewang Zhao • Daxin Ren • Kunmin Zhao • Pan Sun • Xinglin Guo • Liming Liu



Abstract: Ultrasonic welding is an effective ways to achieve a non-reactive/immiscible heterogeneous metal connection, such as the connection of magnesium alloy and titanium alloy. But the thermal mechanism of magnesium alloy/titanium alloy ultrasonic welding has not been defined clearly. In this paper, the experimental and the finite element analysis were adopted to study the thermal mechanism during welding. Through the test, the temperature variation law during the welding process is obtained, and the accuracy of the finite element model is verified. The microscopic analysis indicates that at the welding time of 0.5 s, the magnesium alloy in the center of the solder joint is partially melted and generates the liquid phase. Through the finite element analysis, the friction coefficient of the magnesium–titanium ultrasonic welding interface can be considered as an average constant value of 0.28. The maximum temperature at the interface can exceed 600 °C to reach the melting point temperature of the magnesium alloy. The plastic deformation begins after 0.35 s and occurs at the magnesium side at the center of the interface.

Advanced Transportation Equipment

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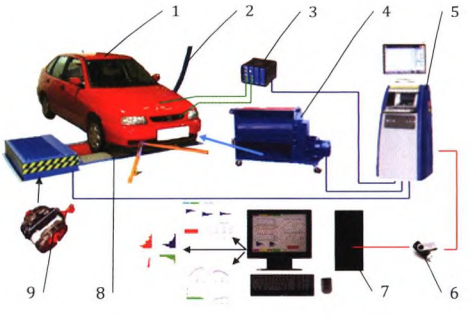
New Leiderman-Khlystov Coefficients for Estimating Engine Full Load Characteristics and Performance. Dariusz Szpica

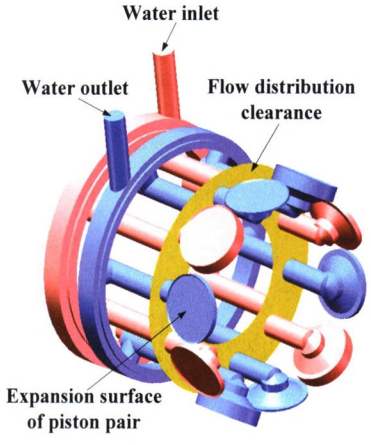


Abstract: The paper presents a method of calculating the full load engine characteristics based on the Leiderman-Khlystov relation. Because the values of the coefficients of the discussed function available in literature were determined for obsolete engine designs, an attempt was made to update them. To this end, a chassis dynamometer was used where a database of results had been built for a variety of vehicles. Following the data collection, the coefficients for variety of fueling system (six groups: fuel injected gasoline and turbocharged gasoline, spark ignition LPG I-II and IV generation, naturally aspirated diesel and turbocharged diesel) were determined. The identification of the coefficients was carried out in Matlab-Simulink indicating the applicability of the said function for most of the engines, yet the recent popularity of turbocharged gasoline engines requires an additional analysis of the possibility of use of a different functional description. The full load engine characteristics is a basis for the vehicle performance characteristics and, further, for modeling of traffic in a variety of aspects of the vehicle operation.

CONTENTS

Vol. 32, December, 2019

Ocean Engineering Equipment



(2019)32:108
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Distribution Performance Analysis and Experimental Research on the Port Plate Pairs of Low Speed High Torque Seawater Hydraulic Motor.

Zhiqiang Wang • Shaofeng Wu • Dianrong Gao • Shuncai Wang

Abstract: The current research of seawater hydraulic motor mainly focused on piston motor and vane motor, but seldom regarded low speed high torque seawater hydraulic motor. Low speed high torque seawater hydraulic motor as a kind of energy conversion device and actuator plays an important role in seawater hydraulic transmission system. However, the physical and chemical properties of seawater, such as low viscosity, high causticity and poor lubrication, result in numerous problems. In this paper, the flow distribution characteristics of port plate pairs for the seawater hydraulic motor are investigated, and the leakage flow and power loss models of port plate pairs are established. Numerical simulations are carried out to examine the effects of water film, inlet pressure and rotating speed on the pressure distribution and leakage flow. And the friction and wear tests of port plate pairs are also carried out. Moreover, the test system of the seawater hydraulic motor is constructed and the performance of prototype with no-load or loading is conducted. The results indicate that the clearance of port plate pairs and inlet pressure have a significant effect on distribution characteristics, but the effect of rotating speed is not very obvious. The experimental results show that the minimum error rate can be maintained within 0.3% by the proposed flow model and the counter materials of 316L against carbon-fiber-reinforced polyetheretherketone (CFRPEEK) are suitable for the port plate pairs of seawater hydraulic motor. Finally, based on the seawater hydraulic experiment platform, the volumetric efficiency of no-load and loading are obtained that the maximum can achieve 94.71% and 90.14%, respectively. This research work may improve the flow distribution performance, lubrication and the friction and wear properties, enhance energy converting efficiency of port plate pair and provide theoretical and technical support for the design of high-performance water hydraulic components.

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