Mechanisms and Machine Science

Hao Zhang · Yongjian Ji ·
Tongtong Liu · Xiuquan Sun ·
Andrew David Ball *Editors*

Proceedings of TEPEN 2022

Efficiency and Performance Engineering Network

Springer

Mechanisms and Machine Science 129

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Indexed by SCOPUS and Google Scholar.

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ISSN 2211-0984 ISSN 2211-0992 (electronic)
Mechanisms and Machine Science
ISBN 978-3-031-26192-3 ISBN 978-3-031-26193-0 (eBook)
https://doi.org/10.1007/978-3-031-26193-0

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

Beijing Information Science & Technology University and Inner Mongolia University of Science & Technology jointly organised the 2022 International Conference of The Efficiency and Performance Engineering Network (TEPEN 2022) in Baotou City, Inner Mongolia Autonomous Region, China, during 18–21 August 2022.

The goal of TEPEN 2022 is to provide a common platform by which professionals, engineers, practitioners and researchers working in the field of condition monitoring, plant maintenance and reliability can share their experiences. The scope of the conference covered a broad area with multi-disciplinary interests in the fields of plant maintenance, asset management, reliability, condition monitoring and related areas, ranging from fundamental research to real-world applications.

In this conference, participations and contributions were involved in both theoretical research and practical applications of all aspects of fault detection, diagnostics, prognostics in both the operational and manufacturing processes. In the course of this event, eight keynote speeches and parallel technical sessions were delivered in accordance with key following topics:

- Vibro-acoustics Monitoring
- Asset Management
- Condition-based Maintenance
- Condition Monitoring and Reengineering
- eMaintenance, Mobile Technology
- Health, Safety and Environment
- Sensors and Instrumentation
- Life Cycle Cost Optimisation
- Machine Health Monitoring
- Machine Lube Oil Analysis and Monitoring
- Artificial intelligence, Machine Learning
- Electrical Vehicle Monitoring, Energy Management
- Maintenance Auditing
- Prognostics and Health Management
- Maintenance Organisation
- Maintenance Performance Measurement
- Non-destructive Testing
- Manufacturing Process Monitoring
- Reliability, Maintainability and Risk
- Signal and Image Processing Methods

Despite the challenging circumstances of year 2022, this book consists nonetheless of 98 peer-reviewed papers. The book offers the state of the art of advances in asset management and condition monitoring and also serves as an excellent reference work for academic and industrial scientists and graduate students, working in asset management, condition monitoring and related areas.

The editors would like to acknowledge and thank the following people for help in book initiation, preparation and completion:

- Shijie Yu (China)
- Jianguo Wang (China)
- Fulei Chu (China)
- Fengshou Gu (United Kingdom)
- Hongjun Wang (China)
- Chao Zhang (China)
- Tianran Lin (China)
- Weihua Li (China)
- Guojin Feng (China)
- Rongfeng Deng (China)
- Zuolu Wang (United Kingdom)
- Yuandong Xu (United Kingdom)
- Xiaoxia Liang (China)
- Jianjun Li (China)
- Jingyi Xing (China)
- Liting Wang (China)
- Jing Zhang (China)
- Wenyan Zhu (China)
- Haiguang Li (China)
- Dawei Shi (United Kingdom)
- Xinghe Wang (China)

Thank you.

Hao Zhang
Yongjian Ji
Tongtong Liu
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Contents

Numerical Study of Resistance Projection Welding of Nuts

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Abstract. The resistance projection welding (RPW) of nuts using the pneumatic electrode force system was subjected to thorough numerical and experimental analysis, enabling the identification of the processing window of welding parameters due to its importance of in the auto manufacturing. The purpose of this study is to study the influence of process parameters like welding currents, welding time and electrode pressure on the properties and microstructure of welding joint of nut in resistance projection welding. To enhance the understanding the microstructure transformation of metal structure during welding, a commercial finite element software COMSOL is used to build 2D&3D models for the numerical simulation analysis of the process. Several parameters that affect the microstructure and strength of the joint, such as welding time, welding current and electrode pressure, are analyzed and the optimized values are recommended. The sensitivity of temperature to electrode voltage is found, which can be used to optimize process parameters.

Keywords: Welding parameters · Resistance projection welding · FEM simulation

1 Introduction

Resistance projection welding of bolts and nuts to sheets is an important manufacturing process in the automotive manufacturing. As mentioned by some researchers, advanced car bodies contain approximately 300 welded and clamped fasteners, e.g., bolts and nuts, to which key safety features including seat belts, steering columns or the earthing of electric circuits are fastened. Thus, the quality of the attachment of these fasteners to the stamped body of vehicles is essential as regards the safety and reliability of end products [1, 2]. While the projection welding of nuts is used widely in auto industry for its virtues of high speed, green and limited heat effect on the parts, it is also characterized by some disadvantages and limitations, including narrow window of processing parameters, lack of repeatability, sensitivity to the lack of tolerance in relation to the height of the projection and the hardness of the material subjected to welding [1]. These limitations may cause deteriorated quality of products.

As the quality of resistance projection welding is closely related to some welding variables such as electrode force, welding current, and welding time during welding

H. Zhang et al. (Eds.): TEPEN 2022, MMS 129, pp. 1–11, 2023.
https://doi.org/10.1007/978-3-031-26193-0_1

process. Low currents cause insufficient heating in weld surface and results in insufficient nugget size, while excessively high current results in defective welding such as surface flash and expulsion. Low electrode force generates expulsion as the small projection collapse leads to concentrated heat generation and expulsion, while a high electrode force leads to insufficient heat generation and small nugget size [2]. Therefore, it is important to understand the welding mechanism of resistance projection welding. Many researchers have contributed lots of efforts in this field. Cunningham and Begeman looked into welding behavior using high-speed photography [3]. Harris and Riley conducted RPW experiments to recommend the suitable values of welding variables and proposed an optimal projection shape with plate thickness [4]. As resistance project welding is a complicated process as the effects of electricity, heat and stress involve simultaneously at the projection; and the nugget along welding surface forms in a few milliseconds, it is hard to capture the changes in the process accurately. To overcome such limitations, it is natural for researchers to simulate the welding process with numerical methods. Sun built a 2D axisymmetric finite element (FE) model simulating projection collapse and nugget forming in the process, the influence of the height of projections on the nugget formation was studied in his paper [5, 6]. C.V. Nielsen et al built a 3D model of projection welding of square nuts to sheets by SORPAS 3D software, focusing on the effect of friction force between nut projection and sheet [7]. Mikno also built 2D&3D models to explore the mechanism during process, with his attention on the difference between the electromechanical and pneumatic electrode force system [1, 8]. Even though many efforts have been put in this field, the results got are usually limited to specific materials and process parameters, there is still no model which has potential of general application. The reason for this may be because the material behavior in the process of RPW is very complicated, involving various factors such as electricity, heat, mechanical deformation, metallurgical elements, and residual stresses around projection after the forming process. And up to now, there is no clear theory about the contact resistance between the projection and the plate, which is important for controlling the temperature near welding line. To understand the variations of the process better, the influence of heat, electricity, stress on the material studied need to be fully coupled. In this paper, a triple coupled model to study the RPW of nuts to sheets is set up using the commercial code COMSOL, which is widely known for its abilities to couple multiple physical fields.

2 Theory of Electro-Thermo-Mechanical Modeling

The numerical modeling of the projection welding of square nuts to sheets was performed by means of the finite element computer program COMSOL multi-physics developed by COMSOL Ltd. The reason for choosing it is because of its open and flexible interface and its reputation on multi-fields modeling ability.

2.1 Mechanical Module

The mechanical module calculates the deformation of the welded part, including the stress and strain along the contact interfaces. The formulation is based on the following variational form [9],

$$\int_V \overline{\sigma}\delta\dot{\overline{\varepsilon}} \quad dV + K\int_V \dot{\varepsilon}_{ii}\delta\dot{\varepsilon}_{jj} \quad dV - \int_{st} t_i\delta u_i \quad dS = 0 \tag{1}$$

where V is the domain volume limited by the surfaces S_u and S_t, where velocities u_i and tractions t_i are prescribed, $\tilde{\sigma}$ is the effective stress and $\dot{\overline{\varepsilon}}$ is the effective plastic strain rate. K is a large positive number, used as a penalty factor to impose incompressibility requirement.

The frictional stress between contact surfaces is modeled by Coulomb law, $\tau_f = \mu\sigma_n$. The direction of the frictional stress is opposite to the relative sliding velocity between the two sliding surfaces.

2.2 Thermal Module

The thermal module calculates heat generation and heat transfer in order to model the effects of temperature increase due to plastic work, heat generated by electrical Joule heating and temperature variation due to exchange of heat with the surrounding environment. The governing equation of the thermal module is built upon the heat transfer equation, which can be written as follows,

$$\int kT_{,i}\delta T_{,i}dV + \int \rho_m C_m \dot{T}\delta TdV - \int \dot{q}\delta TdV - \int kT_{,n}dS = 0 \tag{2}$$

where k is the thermal conductivity, ρ_m is the mass density and C_m is the heat capacity, and the rate of heat generation $\dot{q}$ includes the impact of heat flux from electrical heating, convection, radiation and plastic deformation of welding metals.

2.3 Electrical Module

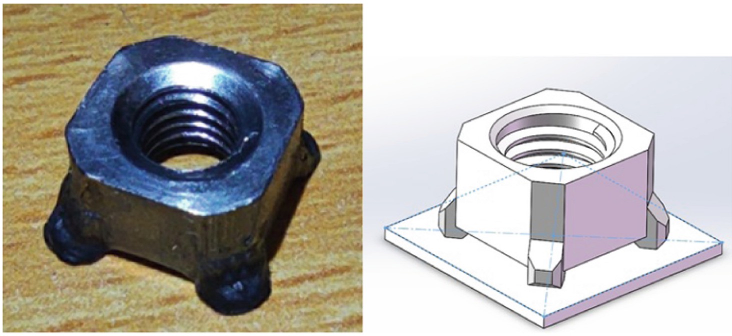
The electrical module calculates the distribution of the electric potential Φ which is necessary to generate the current density through the parts to be welded. The governing equation of the electrical module is built upon integration of Laplace's equation for an arbitrary variation of the electric potential and applying the divergence theorem,

$$\int_v \Phi_{,i}\delta\Phi_{,i}dV = \int_S \Phi_{,n}dS \tag{3}$$

where $\Phi_{,n}$ is the normal gradient of the electric potential to the free surfaces, which is zero and thereby leading to a zero right hand side [7].

2.4 Modeling Conditions

The geometry model set up in the FEM software and its picture of corresponding real part are shown in Fig. 1. A total of nearly 10000 tetrahedral elements is adopted for discretizing the nut, the size of which is around 12 × 12 × 8.5 mm.



(a) (b)

Fig. 1. a. A nut frequently used in RPW process. **b.** The 3D geometry model for FEM analysis.

To simplify model and save time of simulation, a 2D axis-symmetrical model is also built, which could give a clear picture about the formation of nugget, as shown in Fig. 2 (Table 1).

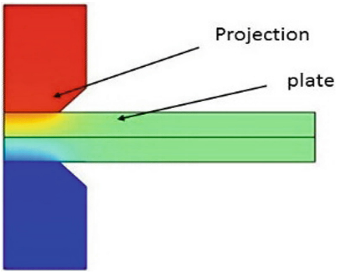


Fig. 2. An axis-symmetrical model of projection welding.

Table 1. The properties of material used in simulation.

Types of materials	Heat conductivity coefficient	Heat capacity	Young's modulus	Electrical conductivity	Poisson ratio	Thermal expansivity
AISI 1010	44.5[W/(m•K)]	475[J/(kg•K)]	200×10^9 [Pa]	9.93×10^6 [S/m]	0.3	1.28×10^{-5}/°C

Table 2. Parameters used in simulation.

Initial squeeze	Heating time	Cooling time	Current	Electrode pressure
0.7 s	0.2 s	0.3 s	8KA–10KA	2–5KN

The parameters used in simulation is consistent with those in actual production. The typical scope of parameters for the simulation of RPW is presented in Table 2.

As the projection of the nut will undergo plastic deformation during resistance projection welding, it is necessary to have information of flow stress of mild steel under high temperature during calculation. The relationship of flow stress of mild steel and temperature is described in Fig. 3. The flow stress of material drops significantly with the rise of temperature. To accelerate the convergence of the iteration in calculation of plastic deformation, the hardening effect of strain rate effect is also taken into consideration.

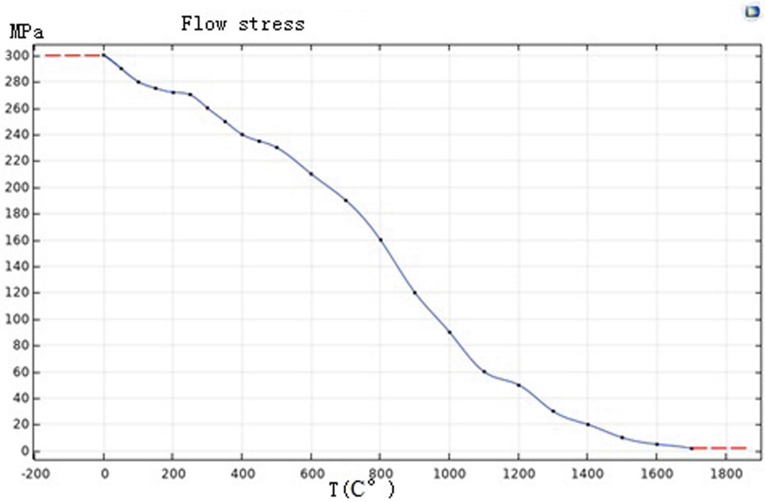


Fig. 3. Flow stress of mild steel vs. temperature.

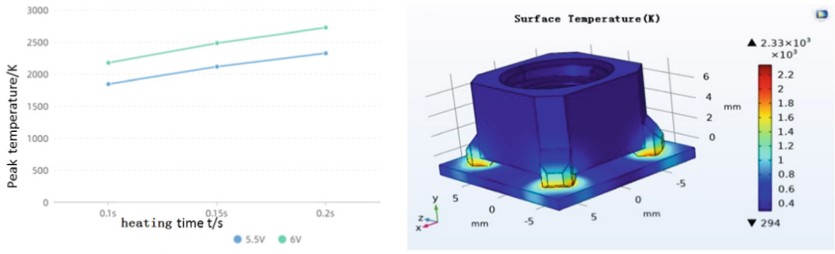
The numerical simulation was performed through a succession of time increments using transient mode in COMSOL and the overall computing time for a typical analysis was around 10 h on a computer equipped with one Intel Xeon 2.4 GHz processor.

3 Results and Discussion

3.1 Effect of Heating Time

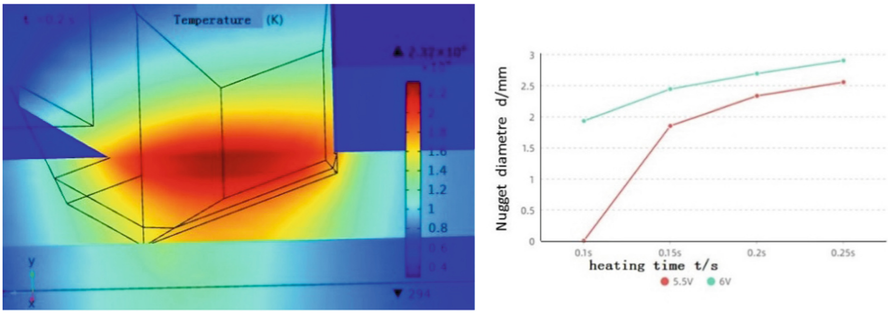
Heating time refers to the time interval when electrical current is applied in the welding process. Increasing the heating time means more energy input into the welding interface, the temperature will be higher. The temperature field is simulated with the voltages is set at 5.5 V and 6 V respectively. The peak temperature increases with the increase of heating time (Fig. 4).

The variation law of molten core diameter with heating time was obtained by simulation as shown in Fig. 5b. The welding current was kept constant, and the heating time t was set as 0.1 s, 0.15 s and 0.2 s respectively. It can be seen from the figure that with the increase of heating time, the generated heat increases and the molten core diameter



(a) (b)

Fig. 4. **a.** Peak temperature vs. heating time. **b.** Temperature distribution of nut in RPW.



(a) (b)

Fig. 5. **a.** A section of projection near welding surface. **b**. Nugget diameter vs. heating time

increases. When the welding time is the same, the diameter of molten core is larger when the welding voltage is larger.

When the heating time was set as t = 0.2 s, the electrode pressure was set as 2000N, and five parameter values from 5 V to 7 V were selected for resistance projection welding experiment. COMSOL software was used to simulate the projection welding with the same parameters, and the simulation results of molten core diameter after welding were obtained. Figure 6 shows the comparison between simulation results experimental results in literature [10]. The nugget diameter grows with the increase of the electrical potential applied. As can be seen from the figure, the change trend of molten core diameter simulated by COMSOL software agrees well that obtained by experiment, and the error between simulation and experimental results is no more than 5%.

Welding heat affected zone (HAZ) refers to the area where, under the influence of a large amount of welding heat input, there is no melting phenomenon on both sides of the weld, which is still in solid state, but has undergone changes in microstructure and performance. Welding heat affected zone (HAZ) is usually small local area, but due to the changes in the microstructure and properties, it is of great significance to explore the HAZ for the performance after welding.

According to the phase diagram of Fe-C alloy, the heat affected zone begins to form when the temperature reaches 727 °C. The resistance projection welding is completed in an instant. It can be considered that the time for transformation is not enough at 727 °C.

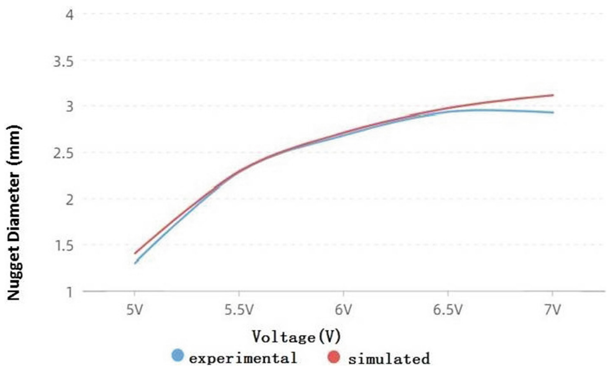


Fig. 6. Comparison of simulated nugget diameter with experimental value.

Therefore, the interval from 800 °C to 1500 °C (1100K to 1800K) is taken as the heat affected zone in this study.

The variation of welding heat affected zone (HAZ) width with heating time was obtained by COMSOL simulation, as shown in Fig. 7. The heating time t takes three values: 0.2 s, 0.25 s and 0.3 s, the welding voltage 5.5 V and 6 V, and the pressure load is 2000N. It can be seen from the figure that with the increase of the welding time, the width of the heat affected zone increases, and the width of the heat affected zone is larger when the welding voltage is small at the same welding time point. The difference between the maximum value and the minimum value is 0.1 mm.

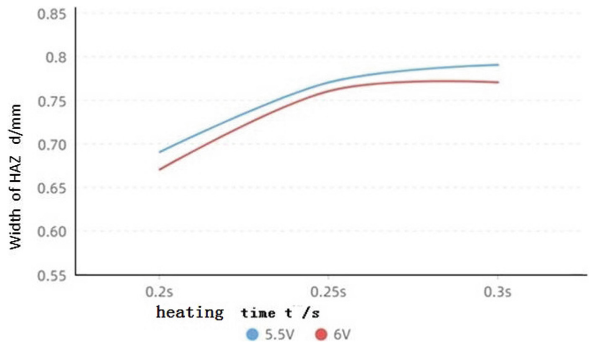
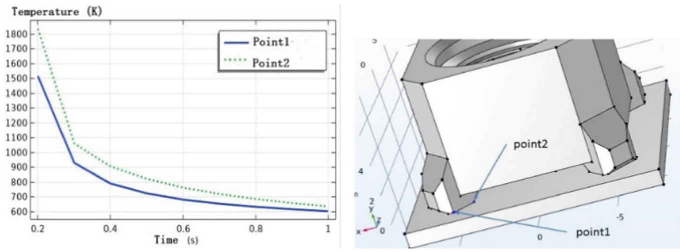


Fig. 7. The width of HAZ vs. welding time.

The heating is stopped when the electricity is cut off and the cooling stage of metals begins. Two points are selected for analysis, point1 in the center of nugget, while point 2 is outside melting area. Theirs cooling stages are also calculated and illustrated in Fig. 8. As can be seen from the figure, due to the rapid heat conduction of the copper electrode, the temperature at both points drops sharply at the beginning and finally approaches to room temperature, the average cooling rate at the beginning of the cooling stage is around 1000 °C/s.



(a) (b)

Fig. 8. **a.** Cooling curves for the points in welding area. **b.** Position of the points.

3.2 Effect of Electrode Pressure on Temperature Field

The electrode pressure's effect on the variation of the maximum temperature of the welded joint is also simulated with COMSOL software, as shown in Fig. 9 below. The selected heating time is 0.2 s, the voltage is set as 5.5 V, 4.5 V, and the electrode pressure is as 0N, 333N, 666N, 1000N, 1333N, 1666N, 2000N respectively. As can be seen from the figure, while the maximum welding temperature decreases with the increase of electrode pressure, there is no significant temperature change. The reason may be while the electrode pressure increases, the contact area between the nut and the steel plate increases, the contact resistance decreases, and the input heat Q decreases. Therefore, the overall heating energy input into the process is kept nearly constant. The similar trend can also be found for the nugget diameter and size of HAZ.

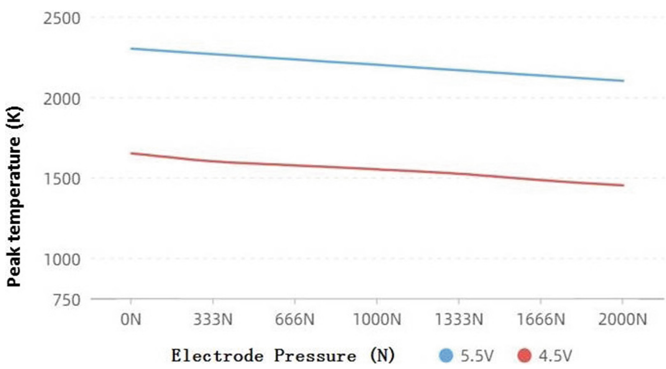
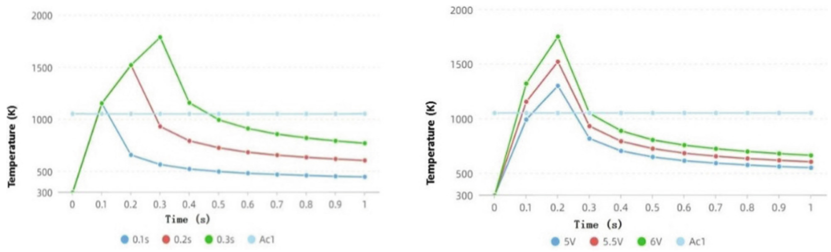


Fig. 9. The peak temperature varies with electrode pressure.

3.3 The Trace of the Point in HAZ

According to some previous study, the properties in HAZ could have important influence to the welding products, it sometimes could even be the weak point. In this study, the point2 in Fig. 8, which is in the area of HAZ, is selected to trace its thermal history to bring more understanding in this field, as shown in Fig. 10. In the figure, the Ac1 temperature line (1100K) represents the austenization temperature of mild steel. It can be assumed that the longer the austenization time of point2 under a certain welding parameter, the wider the width of the heat affected zone of the welded joint under this parameter, and the wider of the nugget of the weldings. It can also be found that the austenization time becomes longer with the increase of welding electrode voltage, the width of HAZ will be bigger.



(a) (b)

Fig. 10. **a.** Thermal history of HAZ vs. heating time. **b.** Thermal history of HAZ vs. voltage applied.

3.4 Effect of Welding Electrode Voltage on Temperature Field

In this study, it is found that the temperature field is very sensitive to the welding voltage applied on the electrode. According to Joule's law, heat generated by electricity, $= I^2Rt = U^2t/R$, Heat is proportional to voltage and current during the welding process. When the welding voltage is changed, the welding current is also changed. The temperature field is directly proportional to the welding voltage applied. It can also be seen from the simulated potential diagram of 2D model in Fig. 10 that voltage drop mainly happens near the area of the welding interfaces, that means the biggest part of the electrical energy is consumed at the welding interfaces, so it is reasonable to find that the temperature field is proportional to the welding voltage. When the voltage exceeds a certain value, it will lead to splash and produce the smaller nugget. According to the calculation results in this model, the temperature near the welding surfaces is not sensitive to the electrical current density, which is quite different from other researchers. The possible reason may be the contact resistance between the electrode and nut is not considered in this model. And the results from the calculation may hint that adjusting the electrode voltage instead of current density could be another way to control process parameters (Fig. 11).

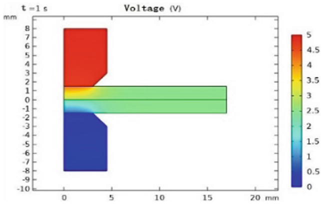


Fig. 11. The voltage distribution of welding parts (time t = 1 s).

4 Conclusions

The following points are concluded from the research:

1. The influence of heating time, welding voltage and electrode pressure on the parameters of process like the nugget diameter and width of the heat affected zone of the welded joint is in order from the largest to the smallest. The longer the heating time, the higher the welding voltage, the lower the electrode pressure, the larger the nugget, the wider the heat affected zone.
2. The simulation results show that the ideal welding parameters for the current setting is as follows, heating time, 0.2S, the electric potential of 5.5V, electrode pressure, 2000N, the current density of 10000A/m^2.
3. The sensitivity of welding interface temperature on the electrode voltage exerted provide possibility to optimize welding conditions through adjusting electrical potential applied.

Acknowledgements. The authors are grateful to the financial support by the science and technology planning project in Guangdong province, China (No. 2017A010102020).

References

1. Mikno, Z.: Projection welding of nuts involving the use of electromechanical and pneumatic electrode force. Int. J. Adv. Manuf. Technol. **99**(5–8), 1405–1425 (2018). https://doi.org/10.1007/s00170-018-2525-5
2. Ha, S., Murugan, S.P., Marimuthu, K.P., et al.: Estimation of lobe curve with material strength in resistance projection welding. J. Mater. Process. Tech. **263**, 101–111 (2019)
3. Cunningham, A., Begeman, M.L.: A fundamental study of projection welding using high speed photography. Weld. J. **44**, 381–384 (1965)
4. Harris, J.F., Riley, J.J.: Projection welding low-carbon steel using embossed projects. Weld. J. **40**, 363–376 (1961)
5. Sun, X.: Modeling of projection welding processes using coupled finite element analysis. Weld. J. **79**, 224–251 (2000)
6. Mikno, X.S.: Effect of projection height on projection collapse and nugget formation – a finite element study. Weld. J. **80**, 211–216 (2001)
7. Nielsen, C.V., Zhang, W., Martins, P.A.F., Bay, N.: 3D numerical simulation of projection welding of square nuts to sheets. J. Mater. Proc. Tech. **215**, 171–180 (2015)

8. Mikno, Z.: Projection welding with pneumatic and Servomechanical electrode operating force systems. Weld J. **95**, 286–299 (2016)
9. Chen, C., Kobayashi, S.: Rigid Plastic Finite Element Analysis of Ring Compression. Application of Numerical Methods in Forming Processes, AMD 28. ASME, New York, 163–174 (1978).
10. Zheng, W.: Numerical Simulation and Analysis of the Resistance Spot Welding Process on Ultra-high Strength Hot-stamped Steel, Master thesis, Shanghai Jiao Tong University (2013).

Fault Diagnosis Method of Planetary Gear Based on FFT-DET and BP Neural Network

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Abstract. A method of effectively extracting fault features from vibration signals of planetary gear system and identifying fault state is kicked out in this paper. Firstly, the fast Fourier transform (FFT) method is used to analyze and extract the fault features of the original vibration signal, and the distance evaluation technology (DET) based on the distance between classes is used to select the sensitive fault features; Then, the fault characteristic data is input into BP neural network to train and test the fault diagnosis model; Finally, the gearbox fault test data set of Southeast University is used for fault identification research. The results show that the proposed method has high identification accuracy for different types of faults. The feasibility and superiority of the fault diagnosis method of planetary gear system based on the combination of fft-det and BP neural network are verified in this study, which can provide technical support for the health state evaluation of rolling bearing.

Keywords: Planetary gear · Fault diagnosis · Fast Fourier transform · Distance assessment technology · BP neural network

1 Introduction

With the rapid development of science and technology, the mechanical equipment in all walks of life is becoming more and more sophisticated, and its internal structure is becoming more and more complex. Due to the increasingly complex structure of these mechanical equipment, the internal parts and components are more closely connected. In the process of machine operation, once a part breaks down and is damaged, if no remedial measures are taken and the damage state is allowed to develop, the equipment will not be able to maintain normal operation, resulting in reduced production efficiency, and the machine will be seriously damaged. In the serious case, it will lead to major safety accidents and endanger people's lives. In 2016, a manned helicopter crashed out of control due to gearbox failure, resulting in 11 deaths and 2 missing [1]. Therefore, if the faults of parts and components can be detected and eliminated in time during the

H. Zhang et al. (Eds.): TEPEN 2022, MMS 129, pp. 12–23, 2023.
https://doi.org/10.1007/978-3-031-26193-0_2

maintenance of machinery and equipment, so as to ensure the safe and stable continuous operation of the equipment, the occurrence of such accidents can be effectively avoided.

Planetary gearboxes are widely used in many fields such as wind power generation system, mining machinery, agricultural machinery, metallurgical machinery, aviation, ships, automobiles and metal cutting machine tools because of their advantages such as high transmission ratio, high transmission accuracy, strong load capacity, stable operation and compact structure [2, 3]. Because these industrial machinery and equipment generally operate in the outdoor work, the environment is harsh, long time by the sand, corrosive liquid invasion damage, and the gearbox structure is very complex, so its transmission system is prone to failure. When the gear is damaged, it will affect the efficiency of the transmission system and produce adverse vibration and noise. If the fault is not diagnosed in time, the equipment may have a shutdown accident or even a destructive accident. Especially in today's society, with the rapid development of computer technology, electronics and information technology, all kinds of mechanical equipment have the development trend of large-scale, automation and high-speed. The accidents caused by the failure of gear will bring greater losses to production and society. Therefore, planetary gear box fault diagnosis, especially efficient fault feature extraction and analysis method, to reduce and avoid due to component failure of the whole equipment to stop working, the later maintenance, regular maintenance to according the change of situation and lengthen the service life of the gear box service time and has positive significance [4]. It can effectively protect the energy supply, industrial production and other important links of national economic construction, minimize the economic losses caused by machine failure, effectively reduce the probability of major accidents in industrial production, and play an important role in the development of society.

With the rise and development of artificial intelligence, deep learning is widely used in fault monitoring and diagnosis. Many scholars and engineers have used different intelligent algorithms to optimize neural networks to analyze and study the fault diagnosis problem of gearbox, and have achieved a lot of achievements. Zhang Zhiyu et al. [5] proposed an improved deep belief network (DBN) integrated with attention mechanism for gearbox fault diagnosis under variable working conditions, which effectively solved the problems of difficulty in fault identification and reduced classification accuracy of gearbox operating under variable working conditions. Wu Yingjian et al. [6] adopted the method of feature extraction based on multi-scale fuzzy entropy to process signals from multiple scales without prior knowledge of the gearbox, and its fault classification accuracy was better than that of traditional sample entropy and single feature extraction method in time and frequency domain. Liu Jiansheng et al. [7] used the EMD method to intuitively take and analyze the IMF component of gear fault signals, and combined with BP neural network for fault pattern recognition. Compared with the traditional method, the training error was reduced and the iteration speed was accelerated, but the mode aliasing problem of signals was not solved. Chen Liai et al. [8] combined SOM neural network and BP neural network, and adopted the composite neural network method for gear fault diagnosis, which has high reliability, but this method takes a long time to identify fault categories. Xie Chong [9] et al. proposed a method of VMD and multi-scale permutation entropy based on parameter optimization, which can search for a better