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Research on Measuring Method of Crankshaft Based on Servo Control Mode

Liu Yangpeng[1], **Ding Jianjun**[1], **Cao Jingshu**[2], **Wang Zhen**[1], **Jiang Zhuangde**[1]

[1]The State Key Laboratory for Manufacturing Systems Engineering, Xi'an Jiaotong University, Xi'an 710049, China
[2]SHAANXI FAST GEAR CO.,LTD., Xi'an 710077, China

ABSTRACT
In the conventional measure process of crankshaft, the width of Abbe probe is designed as more than double the eccentricity volume of crank. This even causes the decline of test accuracy due to the probe distortion. This paper proposes a type of servo control mode for measuring crankshaft based on the four-axis motion system. Abbe probe is integrated with Axis motion system. It feeds in a servo way. A mathematical model is developed to ensure the stable contact between probe and workpiece during moving. The results show that, the narrowed Abbe probe will move according to the journal position, thus ensuring a correct contact of probe and journal. By the method, the automatic detection of crankshaft parameters is achieved with high accuracy and efficiency.

KEY WORDS: Servo control mode; Abbe probe; Four axis coordinated motion system; Mathematical model; Crankshaft

1 INTRODUCTION

AS the power source of automobile, engine is the core unit whose condition reflects all aspects of the vehicle. Crankshaft is a critical part that always works for delivering power under dynamic impact loading (GUO Hai, 2017; CHEN Chen, 2017). Its condition directly affects the remaining life of engine, vibration and noise, and determines the performance of engine. As a result, scholars pay great attention on the precision of crankshaft (DAI Jinjin& CHOU Yanyan, 2018; ZHANG. H, 2015; Quan. W, 2006; ZHONG. M. M et al., 2012; FAN. W. X et al., 2007). To enhance the precision of crankshaft, it is necessary to carry out the research of timely and automatic measurement on single process.

To date, the crankshaft manufacturer mainly adopts manual measure methods to test crankshaft. Since the large quantity and short period, the conventional manual measurement is difficult to satisfy the practical manufacture due to the problems of low efficiency, limited projection and low precision (QUAN. W, 2006; LEI. X. Y, 2014). Therefore, with the wide application of non-contact detection and virtual instrument technology in industrial field (JUANG, L. H., WU, M. N., & LIN, S. A., 2017; SURESHKUMAR, A., Muruganand, S., & BALAKRISHNAN, P., 2016; DING Yanrong, 2018), novel measure systems mainly including contact and non-contact methods are developed (HOMMEL-ETAMIC Gmb H, 2009; MARPOSS Co Ltd, 2011; MARPOSS Co Ltd, 2011; MARPOSS Co Ltd, 2011; LI. B. H, 2005; XU. X. D, 2008; LI J, 2012). In these methods, as the representation of non-contact methods, an automatic measure method by CCD is able to automatically detect work-piece under the non-contact condition (YANG Xing, YANG Huan, HAO Pengju, 2017; DING Shuguang& ZHANG Zhengliu, 2016). However, the non-uniform illumination in the practical measurement will lead to virtual photon, thus affecting the precision (LEI. X. Y, 2014). Moreover, this method has high demands for the post data processing. Different from CCD method, although the speed of continuous coordinate measurement is low, the accuracy and reliability is high (ZHANG. H, 2015). Nevertheless, in our long-term application and research on the continuous coordinate measurement, we find the width of Abbe probe is usually designed as more than double the eccentricity volume of crank. In the process of continuous point contact between the probe and workpiece, the probe mostly affords the non-uniform load that easily causes the variation of structure stress, thus leading to low test precision due

CONTACT Ding Jianjun dingjianjun@xjtu.edu.cn

to the probe deformation. As a result, the low moving capability of conventional Abbe probe primarily causes this phenomenon. On the other hand, the four-axis motion system is widely used in the high speed machining center due to its mobility of the translation of three vertical directions and rotation of single direction. The four-axis structure significantly improved the manufactural difficulty on the complex surface. Consequently, if we adopt a suitable way to integrate Abbe probe and our axis motion system, we can enhance the mobility of conventional Abbe probe by adding translation and rotation capability and deducing the mathematical model of servo coordinate transformation. With this manner, the width of Abbe probe can be narrowed and Abbe probe timely stationary contact the surface of workpiece, thus result in higher measure precision.

On the basis of above analysis, this paper takes the main journal and rod journal as the research symbols which are the two important parts of the engine crankshaft in a tractor. This paper proposes a type of servo control mode for measuring the crankshaft based on the four axis coordinated motion system. It is expected to provide a reference for improving the measure precision of crankshaft.

The rest of this paper is organized as follows. In Section 2 we briefly describe the needed Abbe probe, four axis motion systems and the related concept. The original contribution of the paper is presented in Section 3, where we give a detailed description of Abbe probe integrating the four axis motion systems. In Section 4 we briefly illustrate the general information of an experimental plat-form. Then, our method is supplied with how to measure the investigated crankshaft. Conclusions and possible extensions appear in Section 5.

2 BASIC CONCEPT

2.1 Abbe Probe

SERVO track precision scanning probe system, that is Abbe probe, mainly consists of a probe, a servo unit, a flexibly unconstrained servo unit and a driving control unit for integration all of the components. The special control part is also composed by a moving control unit, the grating scale for detecting the position of the servo unit and the unconstrained servo one, an upper computer is connected to both the readings head of grating scale and the servo motor which drives the unconstrained servo unit. The servo unit comprises a base plate, a sliding plate (the first one), a servo motor, a precision guideway and a screw structure. In details, the base plate connects with Y-axis slide by an arm. The unconstrained servo unit is made up of a sliding plate (the second one), a constant force spring and a precision guideway. With these parts, the guideway of unconstrained servo unit is mounted on the first sliding plate while the probe is installed on the second sliding plate. The constant force spring which provides a constant preload and keeps the probe reliably contact with the workpiece is fastened between the first sliding plate and the second one. There are two groups of grating scales setting on the first sliding plate and the second one, which respectively reflect the position of the first slide and the preload of the spring. The two grating scales are connected to the servo motor to be a closed loop feedback system through the motion control components. Therefore, wide range servo tracking measurement can be achieved for the axial direction of Abbe probe.

The structure of Abbe probe is shown in Figure 1, the operating mode is shown as follows. First, the servo unit drives its probe to move and contact the crankshaft, or the probe approach and contact the crankshaft with the move of servo unit. Second, a precision rotating shaft system is applied to drive the crankshaft. During the rotating of a given crankshaft, the position of the servo unit can be timely adjusted according to the position of unconstrained servo unit varying with the lift information of the specified crankshaft.

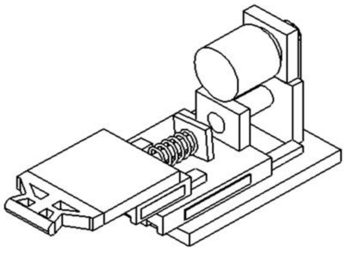

Figure 1. Abbe Probe

This operation drives the unconstrained servo unit moving in the middle of journey on the basis of the probe keeping in touch with the crankshaft. Moreover, the position information of servo unit and the unconstrained one, and the rotating information are collected synchronously. These three types of information are finally integrated to obtain the profile data of the crankshaft.

2.2 Four Axis Coordinated Motion System

The multi axis coordinated system is a prototype measurement device that consists of a mechanical host, a motion control system, a software system, and a probe system. The mechanical host is a four-axis motion system including three linear axes (X, Y and Z) and one rotary axis (C), as shown in Figure 2. The G axis is used to clamp the workpiece.

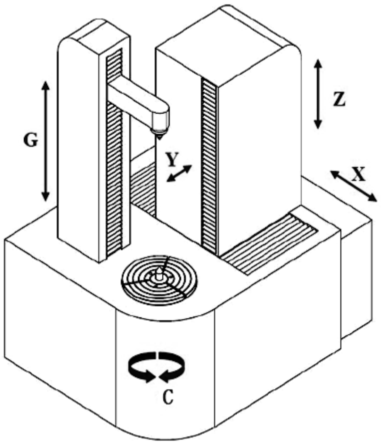

Figure 2. The Configuration of Four-axis Motion System

3 SERVO CONTROL MODE FOR ABBE PROBE

3.1 The structure of servo tracking probe

FIGURE 3 shows the schematic diagram of the structure of servo tracking probe. There are two grating scale installed on the probe. One of them displays the deformation of connected spring. The other shows axial variation of probe. The deformation of reset springs should be highly consistent with each other when the probe is in an arbitrary position. Otherwise, it is difficult to ensure the unique correlation between the measured data and the shape and size of investigated crankshaft. On the contrary, it is easy to recognize the spring deformation as one portion of measured data.

Figure 3. The structure of servo tracking probe

3.2 Servo control movement mode

In the test process of main journal and rod journal, the initial position and height can be random while the initial position mustn't be the transitional fillet. While the main journal is being detected, the probe should be fastened and the deformation of reset spring installed on the probe should be constant. After the basic settings, the main shaft rotates and the probe moves along Z-axis or keeps still. As a result, the route of probe is a spiral or multi-circles. While the rod journal is being detected, the probe is servo controlled. The main shaft rotates while the probe is following and moving along Z-axis. With respect to the rod journal, the route of probe is a spiral or multi-circles.

3.3 Determination of angle standard

There are two methods to install the crankshaft between the upper Center and the lower Center of a measure machine, and search for an angle standard.

(1) Maximal deformation detection based on keyway: A single round parallel located in the maximal radial direction key is designed and installed in the keyway to ensure the top of circle. The probe will detect the crankshaft while rotating. The position which reflects the maximal deformation of the probe will set as the zero point of angle.

(2) Maximal deformation detection based on pin: A pin is installed in the pin hole of crankshaft. Additionally, an auxiliary tool is designed to fit the pin, inducing the pin locates in the maximal external diameter position. The probe will detect the crankshaft while rotating. The position which reflects the maximal deformation of the probe will set as the zero point of angle.

3.4 Determination of initial test point

On the basis of Section 3.3 and for simplifying data processing, we adopt the current position of probe as the initial test position while keeping the center of main journal and rod journal, and the axis of measuring bar in a straight line. The operational procedure can be seen as follows. First, we should adjust the axis of measuring bar and the center of main journal to the same line. Then, the probe should be manually moved near the initial test position. Finally, the control panel should be rotated clockwise for 8°~10°. Additionally, three types of methods are employed to determine the initial test point due to the three types of probe deformation.

(1) If the probe deformation is continuously declined, we can preliminarily determine the range of initial test point by anticlockwise rotating the control panel to find the inflection point that depicts the deformation varying from a large value to a small one. In this area, we can clockwise and anticlockwise rotate the control panel again with 3°~5° to modify the finally initial test point.

(2) If the probe deformation is continuously inclined, we can preliminarily determine the range of initial test point by clockwise rotating the control panel to find the inflection point that depicts the deformation varying from a large value to a small one. In this area, we can clockwise and anticlockwise rotate the control panel again with 3°~5° to modify the finally initial test point.

(3) If the probe deformation is declined and inclined in sequence, we can preliminarily adopt its inflection point as the initial measure point. In this position, we can clockwise and anticlockwise rotate the control panel again with 3°~5° to modify the finally initial test point.

3.5 Measurement Process

When the main journal is measured, the probe is fastened and contacts with the main shaft.

When the rod journal is measured, the projection of servo process of probe position in XOY plan is shown in Figure 3. The marked first place is the current test position. Besides that, the second, third and fourth positions show the route of probe.

According to the servo measure process of probe shown in Figure 4, the rotary table rotates uniformly, X, Y and Z axes follow it, the probe is installed on a translation pairs with a grating scale that can display the axial displacement. To ensure the probe always correct contact with the rod journal and realize the function of servo probe, the following method is adopted:

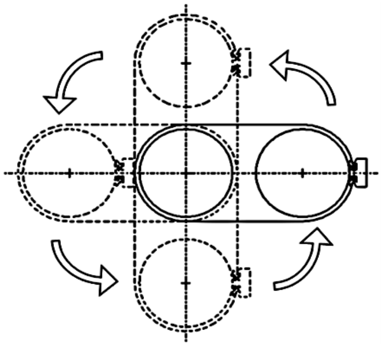

Figure 4. Projection of servo process of probe position in XOY plan

The three-dimensional schematic diagram of the servo probe for measuring the rod journal is illustrated in Figure 5. The current measure position is depicted as the solid lines and the measure position of the main shaft without rotating θ degree is shown by dash lines.

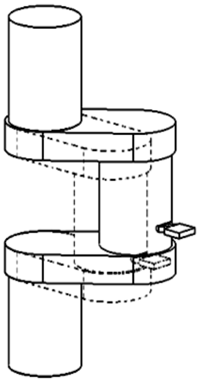

Figure 5. Servo probe for measuring the rod journal

In the measure process of each section of rod journal, method described in Figure 6 is adopted to ensure the correct contact between the rod journal and the probe. The current solid lines represent the projection position of servo probe in XOY plan when the rotary table rotates θ degree. The dash lines present measuring position that without performing θ degree rotation. The coordinate projection of probe satisfies the formula (1).

$$\begin{cases}\Delta X_B = \Delta X_A \\ \Delta Y_B = \Delta Y_A\end{cases} \text{ or } \begin{cases}X_{B1} - X_{B0} = X_{A1} - X_{A0} \\ Y_{B1} - Y_{B0} = Y_{A1} - Y_{A0}\end{cases} \qquad (1)$$

where A0 is the initial position of the center of the rod journal and B0 denotes the initial position of the center of probe when the main shaft arbitrarily rotates θ degree and the three axes are driven uniformly, A0 is changed by A1 and B1 replaces B0 after θ rotation.

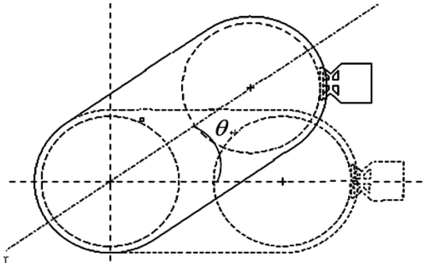

Figure 6. Projection position of servo probe in XOY plan

The projection of probe in YOZ plan is shown in Figure 7. The current solid lines represent the projection position of servo probe in YOZ plan when the rotary table rotates θ degree. The dash lines present the test position without performing θ degree rotation. The coordinate of Z axis for the two positions satisfy the equation (2).

$$\begin{cases}\Delta Z_B = Z_{B1} - Z_{B0} \\ \dfrac{\Delta Z_B}{\theta} = \dfrac{L}{3\times 2\pi}\end{cases} \text{ or } Z_{B1} - Z_{B0} = \frac{\theta \times L}{6\pi} \qquad (2)$$

where L is the effective test length of rod journal whose detailed definition is the axial length of shaft segment that removed both ends of the transitional fillet, the lowest position of each effective length defines the initial position of Z axis, the highest position of effective length is the test end; we formulate B0 as the initial position of probe and update to be B1 after θ degree rotation of the rotary table when the probe moves from the initial position to the final position on Z axial direction and the probe finishes three full rotation relative to the rod journal.

The three axes of X, Y and Z coordinately moves with the linear interpolation method, thus leading to a servo probe.

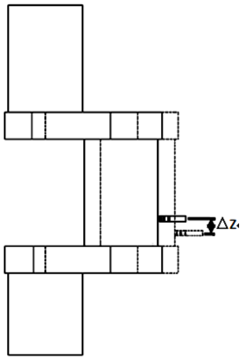

Figure 7. **Projection of probe in YOZ plan**

3.6 Data acquisition and preprocessing

When the probe obtains the data from grating scale, we can integrate the angle information from circular grating of rotary table and synchronous data from Z-axis. The profile information of crankshaft will be obtained. After analyzing the data, different types of error information of indicators will be obtained.

It is necessary to preprocess the measured data since the probe do not strictly move around the center of rod journal. The transformed data will be suitable for the conventional methods. There are two preprocessing methods for the measured data.

(1) Coordinate zeroization of the center of rod journal: The servo probe adopts the conventional test method that the probe rotates relative to the center of rod journal. The difference between the conventional manners is the movable center of rod journal to be measured. For the further convenience of processing, we subtract X and Y value of the center of rod journal from the corresponding whole data without the variation of Z value. Then, the conventional methods can be used to analyze and estimate the different parameters of the transformed data.

(2) Matching of the ideal model of standard workpiece: All of the crankshaft parameters output the matching degree between the actual model and the ideal model expected the diameter which needs to be a true value. Consequently, an ideal model can be established by rotating a standard crankshaft to achieve all of the ideal positions on the rod journal. In the final step, the error information will be obtained by analyzing the actual model and the ideal model.

3.7 The flow of servo control mode for measurement

With the main idea underlying the proposed section 3.1 - 3.6, we present an implementation procedure of servo control mode for measurement in Figure 8 and its detailed process.

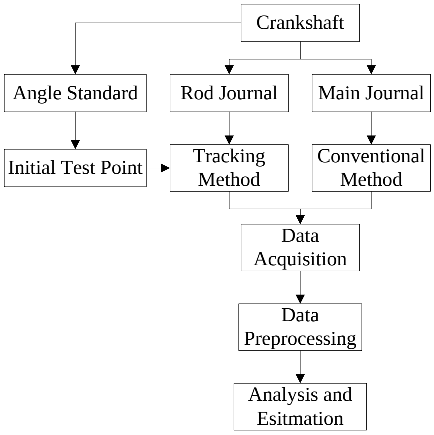

Figure 8. **The servo control mode for measurement**

Steps:

(1) Choose several suitable angle standard test methods according to the crankshaft structure to be measured and decide the final angle standard.

(2) On the basis of the selected angle standard, determine the initial measure point according to the probe deformation.

(3) Detect the rod journal by the tracking measure method and test the main journal by the conventional method.

(4) Obtain the probe data, the angle information from circular grating of rotary table and synchronous data from Z-axis. Obtain the profile information of crankshaft after integrating the three types of information.

(5) Process the measured data by a suitable preprocessing method according to the application requirement.

4 EXPERIMENTAL APPARATUS AND DATA ANALYSIS

4.1 Brief introduction of the test bench

A test bench named tracking mode crankshaft measuring instrument based on four axis coordinated motion system is developed to verify the proposed measuring method. This platform mainly consists of an automatic measuring system and a data processing control system. The automatic measuring system integrates a four axis coordinated motion system and an Abbe probe. In details, the four axis coordinated motion system is formed with three linear axes and a rotary shaft. The linear axes driven by servomotor are composed of a precision rolling guide and a ball screw. The position information of linear axis slide is obtained by the vertical grating produced by Renishaw. The resolution is 0.1 micron. The rotary shaft uses a precision ball bearing, which is driven by a no frame torque motor produced by Kollmorgen. The phase information of the rotary shaft is obtained by the circular grating produced by Heidenhain. The resolution is 1.E-04 degree. Its radial runout error is less than 1 micron. Critically, the Abbe probe is embedded in a rolling guide of the four axis coordinated motion system. In addition, the data processing control system is integrated with the automatic measuring system to control the feed of the mechanical system. The main framework of this apparatus is shown in Figure 9.

Figure 9. **Tracking mode crankshaft measuring instrument based on four axis coordinated motion system**

Moreover, CNC control technology is adopted for the moving of four-axis motion system and position data acquisition. CNC will collect the measured data from Abbe probe timely and ensure the synchronicity between Abbe probe and each position of different shafts.

4.2 *The measurement of an actual crankshaft*

A tractor engine crankshaft with five main journals and four rod journals from China Yituo group co., LTD is used to test the proposed method and hence the developed experimental platform. Some basic parameters such as the theoretical values and tolerances of main journals and rod journals are listed in the first line of Table 1 and Table 2. The test items of main journal are diameter, roundness, cylindricity, run-out, taper, parallelism. According to the practical application, stroke and phase are additional indicators to describing the rod journal. Run-out is deleted in this instance. The test results are depicted in the following part of Table 1 and Table 2.

Table 1. **Test results of main journals**

Items		Diameter	Roundness	Cylindricity	Run-out
Theory		85			
Tolerance	Max	-0.01	0.006	0.006	0.025
	Min	-0.03			
1 Upper		84.9844	0.0038	0.0083	0.0046
1 Middle		84.9847	0.0060		0.0072
1 Lower		84.9892	0.0042		0.0036
2 Upper		84.9835	0.0042	0.0088	0.0066
2 Middle		84.9804	0.0038		0.0089
2 Lower		84.9846	0.0046		0.0072
3 Upper		84.9826	0.0113	0.0130	0.0117
3 Middle		84.9809	0.0094		0.0145
3 Lower		84.9833	0.0121		0.0132
4 Upper		84.9671	0.0092	0.0171	0.0189
4 Middle		84.9744	0.0146		0.0165
4 Lower		84.9756	0.0123		0.0173
5 Upper		84.9660	0.0073	0.0086	0.0070
5 Middle		84.9672	0.0062		0.0048
5 Lower		84.9666	0.0064		0.0062

Items		Taper Error	Parallelism X	Parallelism Y
Tolerance	Max	0.01	0.01	0.01
	Min	-0.01		
1 Upper		0.0036	-0.0024	-0.0005
1 Middle				
1 Lower				
2 Upper		0.0029	-0.0026	0.0005
2 Middle				
2 Lower				
3 Upper		0.0020	-0.0022	-0.0003
3 Middle				
3 Lower				
4 Upper		0.0098	-0.0025	-0.0012
4 Middle				
4 Lower				
5 Upper		0.0056	-0.0039	-0.0024
5 Middle				
5 Lower				

It can be seen in Table 1 and Table 2 that the theoretical diameters of main journal and rod journal are 85cm and 72cm. Each tolerance is derived from the enterprise standards. The following lines of the two tables show the actual test results on the different indicators. In these items, the test of diameter, roundness and cylindricity shows worse than others. Especially the detection of roundness and cylindricity, the values are almost out of the specified tolerance. On the other hand, most of the subsequent items achieve the corresponding tolerance. These global results demonstrate the effectiveness of the proposed method. Whether the size of the crankshaft satisfies the enterprise standards can be detected by the platform.

Table 2. Test results of rod journals

Items		Diameter	Roundness	Cylindricity	Taper Error
Theory		72			
Tolerance	Max	-0.01	0.006	0.006	0.1
	Min	-0.03			-0.1
1 Upper		71.9884	0.0062	0.0086	0.0050
1 Middle		71.9903	0.0074		
1 Lower		71.9925	0.0061		
2 Upper		71.9760	0.0084	0.0103	0.0024
2 Middle		71.9756	0.0090		
2 Lower		71.9774	0.0058		
3 Upper		71.9660	0.0099	0.0373	0.0041
3 Middle		71.9672	0.0098		
3 Lower		71.9706	0.0326		
4 Upper		71.9715	0.0199	0.0243	0.0033
4 Middle		71.9698	0.0216		
4 Lower		71.9747	0.0195		

Items		Stroke Error	Phase Error	Parallelism X	Parallelism Y
Tolerance	Max	0.010	0.3	0.01	0.01
	Min	-0.010	-0.3		
1 Upper		0.0116	0	0.0066	0.0054
1 Middle					
1 Lower					
2 Upper		0.0308	0.0376	-0.0074	0.0012
2 Middle					
2 Lower					
3 Upper		0.0275	0.0696	-0.0090	0.0077
3 Middle					
3 Lower					
4 Upper		-0.016	0.0985	0.0064	-0.0098
4 Middle					
4 Lower					

Compared with Table 2, Table 1 gives a little more satisfactory results. However, the most significant thing is that the same places of the two tables present similar results. Take cylindricity as an example, the values in the corresponding places are approximately equal or within the same order of magnitude at least. It can be also observed that a different test shows different values due to the different test position. These facts explain the fair accuracy condition of the platform. Consequently, the proposed servo control mode is suitable for the practical engineering.

5 CONCLUSION

IN order to improve the structure of Abbe probe and re-duce the intensity of its stress variation, a new type of servo control mode for measuring the crankshaft based on the four axis coordinated motion system is proposed. With theoretical analysis, model construction, platform establishment and its application, some important ad-vantages and comments are given as follows:

(1) Abbe probe and four axis coordinated motion sys-tem can be integrated to realize that Abbe probe enables feed in a servo way of rotation and translation.

(2) The mathematical model of coordinate transformation will ensure a stable contact between the probe and the workpiece surface during moving.

(3) The establishment of experimental platform shows that the integration will narrow the width of Abbe probe, thus ensuring a correct contact of probe and journal.

(4) The application of experimental platform shows the test of crankshaft is realized with high accuracy and efficiency.

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6 REFERENCES

Chen, Chen, (2017). *Research and application of crankshaft manufacturing technology [D]. Hubei University of Technology.*

Dai Jinjin & Chou Yanyan, (2015). *Phase angle detection of multi-crankshaft [J]. Metal processing (cold processing)*, 2018 (05): 49-50.

Ding Shuguang, Zhang Zhengliu, (2016). *Bending detection of crankshaft axis of diesel engine based on machine vision [J]. Combination machine tools and automatic processing technology, (10): 108-111.*

Ding Yanrong. (2018). *Research on Key Methods of Visual Precision Measurement for Axis Workpieces [D]. Jiangnan University.*

Fan. W. X, Zhang. B. C, and Zhang. X. D, (2007). *Optimum of the balance mechanism for a four-cylinder in-line diesel engine. Chinese Internal Combusion Engine Engineering, 28(3), 52-54.*

Guo Hai, (2017). *Design and Research of Crankshaft Automatic Detection System for Vehicle Engine [D]. Xi'an University of Technology.*

Hommel-Etamic Gmb H, (2009). *HOMMEL-ETAMIC shaftscan 1030 Crankshaft and Camshaft Measurement. Jena, Germany: HOMMEL-ETAMIC.*

Juang, L. H., Wu, M. N., & Lin, S. A. (2017). *Gender recognition based on computer vision system. Intelligent Automation and Soft Computing, 1-7.*

Lei. X. Y, (2014). *Research of crankshaft measurement system based on multi-sensor. Shandong University of Technology.*

Li J, (2012). *Design and research on crankcase checking instrument based on grating. Huazhong University of Science and Technology.*

Li. B. H, (2005). *Research on CCD-based and automatic measuring system for crankshaft. Chongqing University.*

Marposs Co Ltd, (2011). *M110 New Automatic Measuring Machine for Checking Shafts[Z]. Bentivoglio, Italy: MARPOSS.*

Marposs Co Ltd, (2011). *M110 Opto Flex Optoelectronic Flexible Measuring Machine for Checking Shafts. Bentivoglio, Italy: MARPOSS.*

Marposs Co Ltd, (2011). *M2016 Flexible Contact Measurement System. Bentivoglio, Italy: MARPOSS.*

Quan. W, (2006). *Development of non-contact automatic measuring system for engine crankshaft. Chongqing University.*

Sureshkumar, A., Muruganand, S., & Balakrishnan, P. (2016). *Design and development of a virtual instrument for hazardous environment monitoring and control using lab view. Intelligent Automation And Soft Computing, 22(1), 12.*

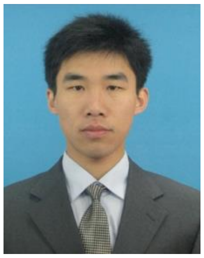
Xu. X. D, (2008). *Study of engine camshaft 3-D measuring method based on compter vision. Shanghai Jiaotong University.*

Yang Xing, Yang Huan, Hao Pengju, (2017). *Research on visual inspection of crankshaft parts based on LabVIEW [J]. Mechanical research and application, 30 (06): 166-168.*

Zhang. H, (2015). *Research of the multi parameters measurement of crankshaft in automobile engine based on shadow casting. Shanghai: Shanghai Jiaotong University.*

Zhong. M. M, Xu. M, and Li. M, (2012). *Research on relationship between manufacturing precision and performance of engine. Machine Building & Automation, 41(6), 31-35.*

7 NOTES ON CONTRIBUTORS



Yangpeng Liu is from Xi'an Jiaotong University in China. He received Bachelor degree in 2004, Master degree in 2007 and Doctor degree in 2017 at Xi'an Jiaotong University. His research interests include precision mechanical design, research on precision measurement and test technology.
Email: Yangpeng.liu@xjtu.edu.cn

Jianjun Ding received Bachelor degree in 2001 and Master degree in 2003 at Central South University and received Doctor degree in 2009 at Xi'an Jiaotong University. He is an associate professor at Xi'an Jiaotong University. His research interests include photoelectric detector, precision measurement and control technology and sophisticated detection complex workpieces. His research results have been applied in a series of industrial products.

Cao Jingshu is from Xi'an Jiaotong University in China. He received Bachelor degree in 2015 at Shanghai University, Master degree in 2018 at Xi'an Jiaotong University. Now he is a research and development engineer in SHAANXI FAST GEAR CO., LTD. His major is design of precision measuring instruments.
Email: 1035155378@qq.com

Zhen Wang is from Xi'an Jiaotong University in China. He received Bachelor degree in 2017 at Xi'an Jiaotong University. Now he is a master student in Xi'an Jiaotong University. His major is Mechanical Engineering.
Email: 1183677354@qq.com

Zhuangde Jiang was born in 1955, Chinese Academy of engineering, Professor, Xi'an Jiaotong University doctoral tutor of two disciplines-Mechanical Engineering and Instrument Science and technology. He received his Ph. D. in 2011 at the University of Birmingham in England. His research areas include micro electro-mechanical systems (MEMS), sensor technology, precision instrument, nanotechnology and ultra-precision fabrication.
Email: zdjiang@xjtu.edu.cn