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HARMONIC ANALYSIS METHOD APPLICATION IN WHEEL SWING ERROR DETECTION LINE SYSTEM

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ABSTRACT

Harmonic analysis method is applied for axial and radial run-out error nature analysis and judgment which affords scientific evidence for improving wheel machining accuracy. At first, this paper introduces the constitute, hardware structure and working principle of wheel swing error detection line system. Through moving mean filter method, axial and radial run-out error of detected wheel is filtered digitally and impact of external noise for detected data is reduced; Secondly Fourier series expansion method is applied to the actual wheel contour harmonic characteristic analysis and the contour characteristics are digitized; finally the actual wheel contour of some component is acquired digitally on detection equipment, and the reason of axial and radial run-out error is analyzed and judged with harmonic Analysis method. This system is applied to the actual wheel production line, which is operated steadily and reliably for 100% axial and radial run-out error of parts online detection. The system detection error is less than 0.1mm.

Keywords: *Harmonic analysis, Radial run-out, Axial Run-out, Wheel*

1. INTRODUCTION

The production technology of luxurious automobiles is one of the important signs of the national science and technology development level, and the automobile Hub is one of key parts which are directly related to the safety and comfort of high- speed vehicles. So the quality demands are becoming the higher and detection methods are becoming the more difficult. Currently, European and American countries require that the accuracy of luxurious automobile hub has been reached the micron level and calculated to forth harmonic. Therefore, only the higher efficiency and intelligent detection methods are applied to mass production of the hub, can it reduce the artificial factors influence on test results, and can it ensure the consistency and accuracy of test results. But the hub quality problems which lead to traffic accidents account for a large proportion, e.g. If the production and manufacture of the automobile hub are unqualified, it will be prone to truck tires and tire burst, which is very dangerous to high-speed vehicles [1].

Imbalance inertia which from axial and radial run-out of vehicle wheel can strike the front and back axle of vehicle periodically and bring the centrifugal force to vehicle wheel. The direction of this centrifugal force, which changes along with wheel rotation, can make wheel beat up and down and swing, then steering wheel is vibrating accordingly by gear steering. This phenomenon can affect dynamic and static characteristic of vehicle severely, which is more obvious if the speed is higher. Because of this wheel manufacture factory all make strict requests for wheel axial and radial run-out detection. For the automobile hub detection, the contour of the body can be obtained through 3D measurement method with the machine vision approach, and then the required demands can be measured [2]. That is to say the 3D model of automobile wheel hub can be structured and measured. The machine vision technology is more mature; considering the cost and using a laser displacement sensor, the relative distance data are used as a standard to judge the quality of the hub. The principle has been applied to measure the pavement roughness successfully [3-5].

In this system, firstly system composition and the detection principle of wheel swing error detection Line are introduced. Secondly the viewpoint is proposed, that the interference noise effects may be eliminated or weakened through moving mean filter method. Thirdly, according to the harmonic analysis methods, the reasons of axial and radial run-out error are analyzed and judged. Finally this system realizes the automatic detection of hub and automatic real-time analysis ensures the detection

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precision, adapting real time data acquisition and processing technology, the closed loop control technology with moving measuring head and measuring axial rotation, and automatic assembling technology of the hub.

2. STRUCTURE OF WHEEL SWING ERROR DETECTION LINE

Wheel swing error detection line is applied for vehicle wheel axial and radial run-out detection, and is designed and manufactured according to QC/T 717-2004"vehicle wheel run-out requirement and detection method". It is mainly composed by one wheel swing error detection machine, lifting rejection device, delivery roller table etc. This also is full-automatic online detection equipment.

2.1 System Constitution

This device has an independent mechanical system, the delivery system, air powered control system, electrical control system.

The device has automatic transmission, testing and manual debugging functions. This electrical control system controlled by industrial personal computer has a display, save and print function for detecting data.

Vehicle swing error detection line, which has automatic loading, automatic clamp, automatic detection, automatic unloading production mode, has an automatic alarm function. If the product is intolerance, the green light is on, the product is delivered on the outlet delivery roller table; If the product is out of the tolerance, the red light is on, and buzzer is ringing simultaneously. Then the nonconforming parts are delivered to rework area through nonconforming parts delivery roller.

Vehicle wheel swing error detection line is full-automatic online detection equipment, see fig. 1 for the actual figure. The whole system is composed by 7 portions, see table1:

Table I: Vehicle Wheel Swing Error Detection Line Composition

No.	Name	Unit	Qty	Comment
1	Inlet delivery roller table	m	1.5	Power-driven roller table
2	Wheel swings error detection machine	Stand	1	Laser detection
3	Outlet delivery roller table	m	1.5	Power-driven roller table
4	Rejection device	Set	1	
5	Non conforming parts delivery roller table	m	2.0	Non power-driven roller table
6	Air power control system	Set	1	
7	Electric control system	Set	1	Industrial control computer control

The variety and specification of the whole detection line are: wheel diameter: (12″~18″), wheel width: (3″~8″). Takt time of detection is: 7 parts/mins (8-9sec/parts), and the product of Axial and radial run-out is detected 100%.

In order to meet detection requirement, the design system error: Axial and radial run-out less than 0.05mm, product repeatability detection less than 0.1mm, principal axis accuracy and end face run-out less than 0.02mm.

2.2 Detection Positions

Selection principle for detection position: select straight line with tyre base width for radial run-out detection; Select straight line at wheel height for axial run-out detection. See figure1:

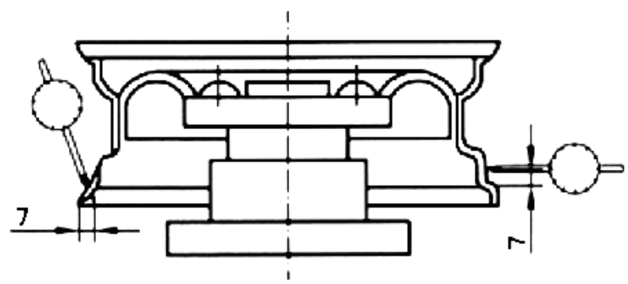

Fig. 1. Detection Position Of A Vehicle Wheel Swings Error

3. WHEEL SWING ERROR HARMONIC ANALYSIS

3.1 Digital Filter

The moving average filter method is adopted in this system. Averaging N sample data, put this average value into the MCU buffer zone, get data just as the push on method, averaging the rest data, improve the data processing speed, reduce occupation for single chip controller. The moving average filter is adopted in this project. Firstly each axial and radial 500 sampling value detected from the internal and external wheel are digitally filtered. Value n is set to 6, every 6 data is averaged and taken as the first sample value, then when every

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sample enters, the earliest detected data is pushed out according to in and out stack method. The result value is averaged as next sample data; In this case, new data is acquired for every sample.

By means of digital filter for sample data, the noise influence is eliminated and weakened, and reliability and accuracy of the detection are improved.

3.2 Harmonic Analysis for Error

Harmonic analysis, in the periodical phenomenon study, automatically recorded experimental data is Expanded to Fourier series, the amplitude of vibration and phase of every harmonic wave is calculated occurred irregular wave is transformed into a serial frequency which has integral multiple superimposed sinusoid. These integral multiple sinusoid curve or the sine wave is harmonic wave [6-8].

According to Fourier transform theory, periodic function can be decomposed into a serial sine wave signal. At the same time that a serial sine wave can be superimposed to a periodic non sinusoidal wave signal. Therefore, it is feasible that the data detected from wheel rotating a circle can be operated as wheel run-out harmonic analysis.

If f(x) was a non sinusoidal periodic function, its period was T, frequency and angular frequency is f and w respectively. Due to a non sinusoidal periodic function in engineering practice meeting Dirichlet conditions in general, it can be expanded into Fourier series. That is

$$\begin{aligned} y = f(x) &= A_0 + A_1\sin(x+\varphi_1) + A_2\sin(2x+\varphi_2) \\ &+ A_3\sin(3x+\varphi_3) + \cdots + A_n\sin(nx+\varphi_n) + \cdots \\ &= A_0 + \sum_{n=1}^{\infty}\sin(nx+\varphi_n) \end{aligned} \quad (1)$$

In which n=1, 2, 3 …

A0, called a DC component or constant component, which all items are sinusoidal quantity that has a different amplitude of vibration and different Initial phase but the frequency in integer relationship $A_1\sin(x+\varphi_1)$ is called first harmonic or fundamental wave, A1, φ_1 is its amplitude of vibration and initial phase; The rest item is called three harmonic and four harmonic etc. Fundamental wave, three harmonic, five harmonic…, they are called odd harmonic; two harmonic, four harmonic…, they are called even harmonics; besides constant component and fundamental wave, the rest items are collectively being referred to as high order harmonic. The form of function (1) can be changed to (2) as follow:

In which：

$$a_n = A_n \sin\phi_n \quad (2)$$

$$b_n = A_n \cos\phi_n \quad (3)$$

$$A_n = \sqrt{a_n^2 + b_n^2} \quad (4)$$

$$\phi_n = arctg(a_n / b_n) \quad (5)$$

Due to the function (2) Infinite trigonometric series, a0, a1, a2..., an, b0, b1, b2..., bn. In function are called Fourier coefficient. From this we can see that, In order to find out the amplitude of vibration and phase ϕ_n of every order harmonic component, Fourier coefficient has to be found out first. Fourier coefficient can be got by integration for general periodic function.

3.3 *Applications of MCL*

In the automobile wheel swing error detection, the encoder is triggered to be a signal, which is installed on the symmetry Shaft of the automobile wheel. In this way, periodic sequence X(n) will be acquired through data acquisition which every unchanged angle of the automobile wheel will trigger the automobile wheel swing error sensor. Then X(n) is calculated by the discrete Fourier transform to acquire each harmonic of the automobile wheel swing error, see formula (6). In order to calculate conveniently and accurately, suppose n is 2M, where M is a positive integer.

$$\begin{aligned} \mathrm{X(n)} &= \frac{a_0}{2} + \sum_{K=1}^{\infty}(a_K\cos\frac{2\pi n}{N} + b_K\sin\frac{2\pi n}{N}K) \\ &= R_0 + \sum_{K=1}^{\infty}A_k\cos(\frac{2\pi n}{N}K + \Phi_K) \end{aligned}$$

(6)

Formula (6) can be achieved by FFT algorithm. FFT algorithm implementation will be introduced as the following with c language

According to in-place computation rules of FFT algorithm, Rotating Factor changes rules and butterfly operation rule will be achieved by with three cycle FFT procedures, the FFT three cycle c language program segments are as follows.

```
for（i=1；i<=m；i++）//1st cycle
{
ie=pow（2，i）；
```

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```
B=ie/2;
pi=3.1415926;
for（j=0；j<=B-1；j++）//2nd cycle
{
p=pow（2，m-i）*j；
ps=2*pi/N*p；
w.reai=cos（ps）；
w.imag=-sin（ps）；
for（k=j；k<=N-1；k=k+ie）//3rd cycle
{
ip=k+B;
t=EE（x[ip]，w）； //multiplication of two Complex Numbers
x[ip].real=x[k].real-t.real；
x[ip].imag=x[k].imag-t.imag；
x[k].real=x[k].real+t.real；
x[k].imag=x[k].imag+t.imag；
}}}
```

This can be obtained by collecting multiple harmonic of automobile wheel data, for example A_0, A_1+iB_1, A_2+iB_2, …, A_K+iB_K. According to symmetry of the FFT results and practical of significance the automobile wheel detection, usually only the data of 0 to 4 harmonics, i.e. A_0, A_1+iB_1, A_2+iB_2, A_3+iB_3, A_4+iB_4. For the signal the point of $K=0$, is a DC component, the amplitude is A_0/N; For the signal the point of $K>0$, the amplitude is $(2*\sqrt{A_K^2+B_K^2})/N$, their phase are same, i.e. $-\arctan(B_K, A_K)$. So we can get the amplitude and phase of each harmonic, which will provide strong the data support with the specific analysis of automobile wheel error.

4. WHEEL RADIUS RUN-OUT ACTUAL DETECTED DATA ANALYSIS

Table 2 is 128 points initial data for detecting someone wheel rotating one circle in detecting practice.

By the data and figure from this portable wheel swing error detection machine, we can conclude that the amplitude of vibration of the first harmonic of this wheel is larger; the amplitude of vibration of the others is too small. That is to say, bias is the main factor for affecting wheel stability. Consequently, by finding the method for correcting bias, the wheel production quality can be improved.

Table Ⅱ
128 Points Data From Some Time Detection Of Radius Run-Out Error

No.	1	2	3	4	5	6	7	8
1-8	0.46	0.65	0.64	0.66	0.61	0.72	0.37	0.41
9-16	0.55	0.43	0.36	0.65	0.43	0.72	0.56	0.37
17-24	0.36	0.50	0.56	0.49	0.54	0.58	0.41	0.46
25-32	0.44	0.59	0.30	0.64	0.47	0.41	0.55	0.49
33-40	0.85	0.98	0.91	0.94	0.84	0.68	0.73	0.81
41-48	0.88	0.94	0.69	0.71	0.81	0.89	0.99	0.84
49-56	0.71	0.70	0.85	0.82	0.75	0.79	0.59	0.80
57-64	0.65	0.54	0.81	0.47	0.53	0.64	0.63	0.72
65-72	0.86	0.72	0.77	0.61	0.83	0.82	0.51	0.72
73-80	0.54	0.51	0.64	0.62	0.74	0.75	0.58	0.80
81-88	0.80	0.85	0.85	0.88	0.70	0.77	0.98	0.83
89-96	0.84	0.91	0.80	0.86	0.88	0.90	0.80	0.76
97-104	0.38	0.42	0.51	0.47	0.67	0.42	0.53	0.35
105-112	0.44	0.51	0.58	0.65	0.53	0.49	0.57	0.50
113-120	0.44	0.41	0.55	0.51	0.68	0.42	0.41	0.51
121-128	0.44	0.40	0.56	0.49	0.51	0.56	0.56	0.48

Table Ⅲ
The Amplitude Of Vibration And Phase Of One Detected Radius Swing Error

Name	1st harmonic	2nd harmonic	3rd harmonic	4th harmonic
Phase/raid	3.09	-2.72	-0.05	0.32
Amp/mm	0.11	0.06	0.08	0.02

In wheel run-out detection practice, the factory main concern is first harmonic and second harmonic. Therefore, we only need to calculate first harmonic and second harmonic data. Amplitude, frequency and phase of wheel radius swing error relation figure See figure 2.

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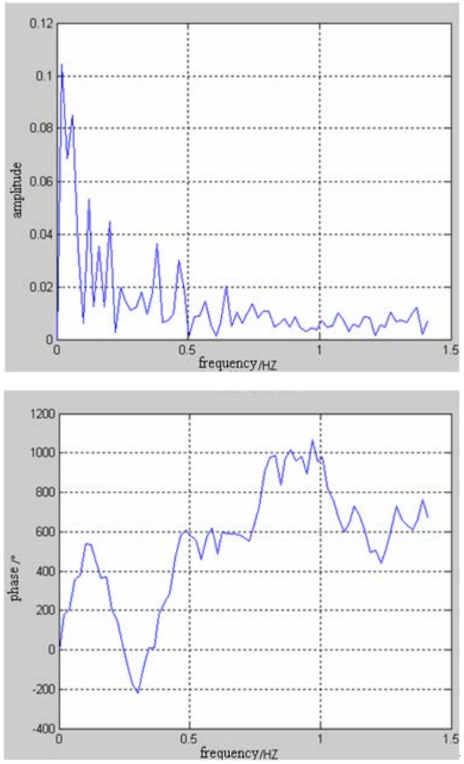

Fig. 2. Amplitude, Frequency And Phase Of Wheel Radius Swing Error Relation Figure

Through the above experiments, we can know that the deviation degree of the exterior contour of the wheel and the motioning wheel. The amplitudes and phase angles value of the first harmonic shows no welding seam, no burr and the local defects on the wheel. That is to say, the wheel is smooth. During the motion process, the center error is 0.11mm between the rotation center of the actual wheel contour and the theoretical design value, which is less than 0.5mm of deviation standard. So the motioning wheel offset of the first harmonic meets the detection demand, which offset angle is 3.09 radian. If the value is becoming bigger, then it could induce the bump of the whole vehicle, namely the stationarity. The amplitude values are 0.06mm, 0.08mm, 0.02mm respectively from the second harmonic to the fourth harmonic. Their physical meanings stand for the approximate degree of the ellipse, tri-edge circle and quadric-edge circle of the wheel exterior contour. Namely the maximum difference value between all kinds of harmonic amplitudes and radius of the wheel basic circle, which is related to the system error of the whole mechanism. Through the contrast, we can see that the amplitude of the first harmonic (0.11mm) is the principle factor. Through the wheel swing error detection mechanism, we may improve the detection precision: the stiffness of the whole body; the repeatability of the rotation spindle, locating and clamping mechanism; the precision and installment error of the axial and radial laser displacement sensor.

5. CONCLUSION

From the above experimental results it can be seen, the proposed detection scheme and the data processing algorithm is reasonable and meets the demand of the project. At present, this detection line has been applied to domestic wheel factory production lines, which is stable and reliable and can be finished 100% axial and radial run-out on-line measurement. Its measurement error is less than 0.1mm.

In this paper, the main works are as follows:

(1) The designed mechanical structure of wheel swing error detection line is very reasonable;

(2) The method is proposed that acquisition data is filtered digitally, which is collected by the laser displacement sensor to reduce the effects of interferences and noises through moving mean filter method;

(3) Fourier series expansion analysis method and digital realization method of the actual wheel contour harmonic characteristic are proposed, namely after discretization combined amplitude method of different order harmonic;

(4) The harmonic analysis method is applied to judge actual axial and radial run-out error feature (or error properties) and analyze the reasons of axial and radial run-out error, which provides the scientific evidence for the machining accuracy of the wheel.

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