Technical Development and Analysis of Four-Wheel Aligner for Automobiles

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Keywords: Four-wheel aligner, technical development, automobile.

Abstract: The development status of four-wheel aligner for automobiles is reviewed in this paper at first. Then the key technology of developing four-wheel aligner is analyzed. Measuring Datum and positioning mode are the base of the aligner model. Measuring principle and its theoretical error are illustrated to enhance the measurement accuracy. Finally this paper gives an outlook to the research of four-wheel aligner.

1 INTRODUCTION

Vehicle wheel alignment parameters which mainly include the kingpin inclination angle, the caster angle, the camber angle, the toe-in angle and the thrust angle reflect the relative position relation between wheel, steering knuckle and front/rear axle. They have important influence on vehicle's handling stability. According to the design requirements, the wheel alignment parameters need to be adjusted in advance, but they will change after a period of driving. Wheel positioning angle deviation from the design value will result in a series of adverse consequences such as abnormal tire wear, fuel consumption increase, and even the car steering difficulties and path offset. As a special equipment for detecting wheel alignment parameters, the four-wheel aligner plays an important role in vehicle maintenance and fault detection.

2 DEVELOPMENT STATUS OF FOUR-WHEEL ALIGNER

With the continuous improvement of the accuracy requirements of the wheel alignment parameters in modern automobile performance testing, the research of four-wheel aligner has been flourishing. At present, there are two kinds of measurement methods for four-wheel aligner used at home and abroad, static measurement and dynamic measurement. Static measurement refers to the mode of detecting the vehicle wheel alignment in the stationary state according to the geometrical relation of the reference point on the center of the wheel. The equipment with this mode mainly includes leveling wheel aligner, pull-line wheel aligner, laser wheel aligner and CCD wheel aligner. The leveling wheel aligner is simple in structure and easy to carry, but it has low precision and can not measure the toe-in angle and the thrust angle. The typical levelling wheel aligner such as Japan's 900A, WAT2000 and domestic GCD-I, and is only suitable for the detection of the front wheel about non-independent suspension trucks (XU Guan, 2009). The pull-line wheel aligner adopts the micro-computer to control the angular displacement sensor to analyze the data, and then realizes the visual display of the data. However, the operation complexity and low precision are still its main drawbacks (LV Xiaojun, 2011). Laser wheel aligner adopts the cooperation of the lasers and wheel mounted jigs to capture signals. It can neither be used to accurately measure nor rapidly detect because of the narrow beam and the limited range, therefore laser wheel aligner has been abandoned in the developed countries of the automotive industry. As an advanced wheel aligner, CCD wheel aligner integrates with a new type of semiconductor integrated optoelectronic device, which makes it wide utilization and high precision. Whereas there are also disadvantages such as high manufacturing cost and complex maintenance (DAI Renqiang, 2013). At present, this type of wheel aligner manufacturers mainly include HUNTER,

Yu, S., Zhao, F., Zhang, Y. and Huang, X.
Technical Development and Analysis of Four-wheel Aligner for Automobiles.
In *3rd International Conference on Electromechanical Control Technology and Transportation (ICECTT 2018)*, pages 555-559
ISBN: 978-989-758-312-4

JBC, BEISSBATH, CORCHID, Three Jay Yi , and so on.

Dynamic measurement refers to the method of measuring the vehicle wheel alignment in the moving state. The toe-in angle, track width, the wheelbase and the inclination angle are all directly when the vehicle is driving while they are distorted in the stationary state, which are influenced by many factors such as rim distortion, chassis clearance, suspension deformation and heavy load. Thus, the dynamic measurement becomes the mainstream measurement method with higher precision. The 3D wheel aligner is one of the most widely used measurement equipment in the market, which is attributed to its use of three-dimensional dynamic measurement and the fast algorithm to achieve a qualitative leap in principle, precision and real-time, such as the JBC-V3D of the United States, the German BOSCH-FWA4510, etc. The device has many advantages such as high measurement efficiency, accurate measurement and low failure rate.

3 KEY TECHNOLOGY OF DEVELOPING FOUR-WHEEL ALIGNER

3.1 Measuring Datum and Positioning Mode

There are two important rotating axes that affect the four-wheel alignment, the steering axis of steering wheel when turning and the rolling axis of the wheel. Among them, the kingpin inclination angle and the caster angle are the two-dimensional angle of the steering axis, the camber angle and the toe-in angle are two dimensional angles of the rolling axis (ZHANG Mei, 2008). In addition, the four-wheel positioning datum also comprises a OXY plane of vehicle coordinate system, a geometrical centreline and a thrust line.

The OXY plane refers to a plane formed by the center of the front and rear axles, and the thrust line is an imaginary line obtained from the intersection of the two rear wheels plane and the OXY plane (ZHAO Qiancheng, 2013). The positioning method of the coordinate relation between the four wheels and the suspension in the direction of X, Y and Z axes is called the four-wheel alignment of the thrust line, which takes the angular split line of the toe-in angle of the rear wheel as the body Motion Center, regardless of the body center offset (WEN Dong, 2009). Using the thrust line positioning, the first step is to determine the position of the thrust line by measuring the rear wheel, and then the thrust line is used as reference to adjust the toe-in angle of the directive wheel. When the thrust line does not coincide with the geometrical centerline, the four wheels deviate from the geometrical centerline, which means that the deviation direction and abnormal wear of the tires will appear when the vehicle is running in a straight line.

The geometric centerline is the connection line of the midpoint of the front and rear axle of the vehicle, and it can be used as a reference to adjust the toe-in angle of the wheel. When the rear wheel is in the correct position, the adjustment of the front wheel to the geometric centerline and the thrust line coincide, the positioning effect is the best. Once the rear wheel position is offset or the geometrical centerline is not coincident with the thrust line, the steering performance of the vehicle will be affected. Therefore, the rear wheel alignment will be ignored when the front wheel is adjusted with the geometric centerline as the datum.

For modern four-wheel aligners, most of them have the ability of complete four-wheel alignment. The positioning method of the coordinate relationship between the four wheels and the suspension in the direction of X, Y and Z axes which takes the wheel thrust line as the Body Motion center line is called the complete four-wheel alignment (WEN Dong, 2009). The specific operation is to take the geometric centerline as the datum, and realize the change of the relative position between the thrust line and the geometrical center line by adjusting the thrust angle continuously. When the thrust line is coincident with the geometrical centerline, the thrust line or the geometrical centerline is used as reference, and the wheel alignment is accomplished by adjusting the toe-in angle of the directive wheel. Once the four wheels are adjusted, the direction of each wheel is parallel to the geometric centerline, at which time the vehicle has the best running performance. This method is by far the most ideal adjustment for four-wheel alignment(XU Guan, 2009).

3.2 Measuring Principle of Typical Four-wheel Aligners

The traditional four-wheel aligners ,such as pull-line aligner and laser aligner, all use inclination sensors to measure the kingpin angle and the camber angle directly, and the steering wheel is positioned in the center position before measuring. The measuring beam which forms a closed approximate rectangle around the wheel is emitted by the measuring head of the wheel mounting clamp, and the toe-in can be measured according to the rectangular shape. The kingpin is a virtual axis without a measurement reference and is in a general position in space. The wheel needs to be rotated at a certain angle on the angle plate. Indirect measurements of kingpin angle are made using the measured values of two tilt sensors perpendicular to each other inside the measuring head and then derived by approximate linear equations. The standard stipulates that the accuracy of the camber angle and the toe-in angle measured by the four-wheel aligners is ±2 ', but the accuracy of the kingpin inclination is ±6 '(XU Guan, 2007).

The 3D wheel aligner is currently the most advanced four-wheel alignment equipment, and the main components include computer, high-resolution camera, target board and corner plate. The commonly used target board is mainly planar form, and the traditional high-precision optical electronic sensor is replaced by the reflector as a target. The 3D wheel aligner generally adopts the method of measuring trolley marching, which is divided into three steps (ZHAO Qiancheng,2013). First of all, the wheel of the vehicle is fitted with a target board with a certain pattern, so that it can synchronize with the wheel movement. Secondly, 2 high-resolution cameras are used to capture the image information presented on the target board. Finally, the computer uses the image collector to analyze the wheel's stereo posture, and obtains the position relation of each wheel relative to the measuring datum. The measuring method is simple and rapid, and the non-contact measurement is realized by the four-wheel aligner with the principle of perspective, but it has strict requirements on the shape and sharpness of the image on the target board. The following is the mathematical derivation model of 3D wheel aligner (ZHANG Qixun, 2014).

As shown in Figure 1, the optical axis of the left camera and the right one is a pair of parallel axes, and the distance between the two cameras is recorded as baseline B. When the left and right camera simultaneously observe the same point P, the coordinates of point P are recorded as $p_l(X_l,Y_l)$ and $p_r(X_r,Y_r)$ respectively. Assuming that the image information collected by two cameras is on the same plane and the focal length is f, the mathematical relationship can be derived as follows:

$$\begin{cases} X_l = f x_c / z_c \\ X_r = f(x_c - B)/z_c \\ Y = f y_c / z_c \end{cases} \qquad (1)$$
$$\text{Disparity} = X_l - X_r$$

The space coordinates of point P can be derived by using the formula (2) in the camera coordinate system:

$$\begin{cases} x_c = \frac{BX_l}{Disparity} \\ y_c = \frac{BY}{Disparity} \\ z_c = \frac{Bf}{Disparity} \end{cases} \qquad (2)$$

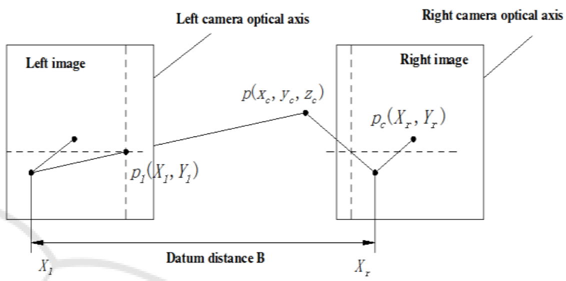

Figure 1: 3D stereoscopic imaging principle

3.3 Error Analysis

As a measuring equipment, the precision of four-wheel aligner is the main criterion to determine its application value. Based on the above analysis, it is concluded that the camber angle and the toe-in angle can be measured directly, so there is no theoretical error and can achieve extremely high precision. However, when measuring the kingpin angle, the approximate linear formula can only be deduced by establishing the space geometry model, and then the wheel alignment parameters are calculated by combining the data obtained by the inclination sensor and the approximate linear formula. However, the linear formula does not reflect the true motion state. Thus, different mathematical models will cause different errors, as well as the actual detection errors, which constitute the main error of the four-wheel aligner. The following deduction is taken as an example of measuring the kingpin inclination angle by using a four-wheel aligner with inclination sensor.

Taking the left front wheel as an example, when the wheel turns left or right to angle δ, the relationship between the kingpin inclination angle β and measurement angle Δω is deduced as follows:

$$\beta = \sum \omega / 2 \sin \delta \qquad (3)$$

The formula (3) indicates that the kingpin inclination angle β is $1/2 \sin\delta$ times that of the actual measurement angle $\sum\Delta\omega$. Using the relationship of $1/2 \sin\delta$ times to set the four-wheel aligner can directly measure the kingpin inclination angle β, then formula (3) is a linear model of the four-wheel aligner with inclination sensor.

However, in the derivation of formula (3), the measurement result of the four-wheel aligner is biased with the real value due to the approximate treatment of the small angle. When considering the effect of the small angle on the result, the following relationships can be obtained:

$$\omega_1 = arcsin\frac{c_1}{\sqrt{1+b_1^2}} - arctan\frac{b_1}{a_1} \quad (4)$$

$$\omega_2 = arcsin\frac{c_2}{\sqrt{1+b_2^2}} - arctan\frac{b_2}{a_2} \quad (5)$$

$$\sum\omega = \omega_1 + \omega_2 \quad (6)$$

Among them, the b_1,c_1,b_2,c_2 are all related to the caster angle γ, the kingpin inclination angle β and the horizontal rotation angle δ.

From the above, it can be seen that the measurement angle $\sum\Delta\omega$ is the function of the caster angle γ, the kingpin inclination angle β and the horizontal rotation angle δ, and the kingpin inclination angle β is obtained by measurement angle $\sum\Delta\omega$, so the kingpin inclination angle β is influenced by the caster angle γ. However, the linear model of the four-wheel aligner with inclination sensor does not consider the caster angle γ, so it has theoretical error to measure it (XU Guan, 2006).

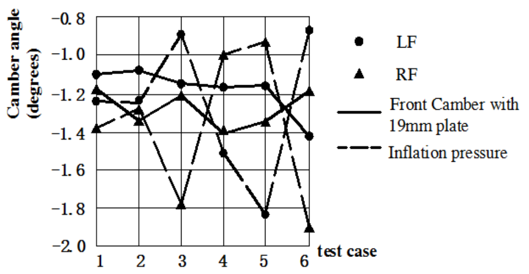

Figure 2: two factors impact on Front Tire Camber

4 CONCLUSION AND DEVELOPMENT TREND

We found that the static wheel alignment measurement is not strongly affected by many of the variables tested. These included, equipment accuracy, suspension preload, and operator. However, the largest effects on wheel alignment accuracy that can be expected to arise in a plant or wheel alignment shop are caused by levelness of the platform and errors in tire pressure (Patel H, 2016) (see Figure 2). Therefore, the four-wheel aligner based on static measurement will pay more attention to the levelness of the platform and tire pressure in the future, while increasing the degree of automation to reduce human participation.

In addition, the four-wheel aligner based on the computer vision measurement technology brings great reform to the traditional wheel alignment (LV Xiaojun, 2011), and the detection equipment with 3D image as the mainstream is gradually replacing the traditional four-wheel aligner. However, while pursuing accurate wheel alignment parameters, other problems also arise. Among them, the diagnosis of large amount of information and uncertain factors are the disadvantages of electronic computing. For the existing four-wheel aligner, the calibration is still subject to artificial adjustment, so it is very important to operate conveniently while ensuring its stability and reliability. In the future market, people no longer only focus on the accuracy of measuring instruments but require as few steps as possible, which aims to reduce the incidental error caused by human operation and shorten the training time of technicians. In this era of rapid development of automobiles, the automobile industry is gradually forming more complete information resources. For the four-wheel aligner, in order to solve the above problems from the root, I believe that the global empirical database will be formed in the near future, at that time automakers and four-wheel aligner manufacturers will work together to develop the best data and upload it. At the same time, in order to achieve the most authentic positioning effect, the four-wheel aligner can be loaded in the car body. When the vehicle is running, the four-wheel aligner will monitor the wheel state in real time and use the network to compare directly with the standard in the database. If the result is outside the standard range, the four-wheel aligner automatically adjusts the wheel to the proper position when the vehicle stops, which realizes the integration of detection and adjustment.

In addition, the new four-wheel aligner can be added to the active safety system. Such a proposed active safety system is a lane departure warning where an driver support system acts as a copilot to monitor lane –keeping performances, and warn the driver when a lane departure is predicted (SG Barhe, 2016). Therefore, the invention of a humanized and intelligent four-wheel aligner based on computer vision measurement technology and ergonomics will become the common goal of future.

ACKNOWLEDGEMENTS

This work is supported by grant 201611058009 of National Training Program of Innovation and Entrepreneurship for Undergraduates.

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