Design of die adjustment component vector decomposition method for metal screw forming

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Abstract. This research focuses on the punch case adjustment vector decomposition problem of metal screw forming machines that occurred frequently in fastener manufacturing. The dimension component vectors of screw forming center axial line misalign for die adjustment were often decided by human experience currently and the adjusted results were not always be satisfied. It is a difficult problem to analyze the punch die adjust component vector from screw specific shape measurement information. This research integrates rotation axial optical measurement instrument and die adjustment mechanical specification information of forming machine then using the proposed sampling process so that the adjustment component vectors with respect to the punch case can be decomposed. The result of this research provides the adjustment guidance that includes main items of misalignment component vector. A practical verification is also demonstrated in this paper by using a type of screw forming machine for showing the feasibility of the designed die adjustment method.

1. Introduction
The most commonly used forming machine punch case adjustment in the metal fastener industry, that is, the die core is installed to the case of the forming machine and then adjusted the punch case posture on the machine. Its advantages are that these types of equipment space are small and the unit price is much lower. But, the disadvantages are forming die center alignment method cannot be systematized and needs to rely on manual experience to adjust the punch die case posture in a machine, hence the current operation method will be difficult to achieve high precision. The common manufacturing alignment method is aligned with designed reference mark [1]-[3], the screw forming related to this research cannot be marked on the screw. One proposed method is the auxiliary adjustment of the engraving mark on the mold [4]. The two molds combination does not use any pin or alignment part, they only use the optical alignment system to align. But, there are still cross marks on the top glass mold and on the bottom metal mold. This method cannot be referred because the inner hole of the die core and the die shell for screw manufacturing are processed by a different process machine. Therefore, this research invests a guidance method to solve this problem to overcome when adjusting the screw forming machine, and to provide an effective method when the production line encounters rapid sample change requirements. It is difficult to adjust the axis alignment between the punch and the forming die while operator adjusts the die case on the forming machine. The fastener manufacturers often use the human operated concentric meter measurement method, but only the maximum mount eccentricity vector of the screw can be obtained. The horizontal and vertical eccentricity components cannot be obtained. The
current method can only be roughly estimated based on the experience of the operator, and accurate adjust information cannot be obtained.

2. Methodologies

In this paper, the information of “image measurement”, “vector decomposition”, “die case mechanical parts”, and the “sampling process design” are integrated to be a die case adjustment guide system. After the adjustment of the equipment, the key dimensions required by the machine are provided with program guidance to complete the die adjustment.

In order to solve the difficulty of adjusting the die case of the screw forming die after the equipment is installed. According to the program of the guiding system, the analysis results of the required head thickness, rod length, eccentric X and eccentric Y are obtained after sampling three screws. Machine operator only needs to complete the adjustments in sequence according to the system guidelines, and one can quickly achieve the required screw die forming size requirements. The implementation methods are described as follows:

2.1. Image measurement
The optical inspection machine (as shown in Figure 1) uses the traditional image projection method to measure the size of the screw which can measure the screw shank diameter, head width, flange width, total length, shank length (or length under head), and head height (or head thickness), head center, rod center, and so on. And an additional rotating mechanism is added to allow the image projection information to rotate through the axis direction, and the maximum value of the sine wave signal minus the minimum value is 2 times the maximum misalignment, which can be analyzed the maximum screw misalignment SVmax value in Figure 2.

![Figure 1. Optical inspection machine.](image)

![Figure 2. Transform the inspection data to screw head and shank misalignment vector.](image)
The most common related dimensions of the adjustment mechanism of the forming machine are head thickness, shank length, and eccentricity. The adjustment amount includes head thickness, shank length, eccentric level (i.e., eccentric X) and eccentric vertical (i.e., eccentric Y). It is different between the head thickness, shank length and the required specifications is quite easy to calculate, the eccentric component related to die adjustment machine is not easy to know. By using measurement instrument one can only know the information of maximum eccentric value. While the screw has been taken out from the forming machine, the relation with respect to the X and Y components from the forming machine and the screw cannot easy to obtain at this situation. This is the next important issue to achieve the required forming specification. This critical issue will be discussed from 2.2 to 2.4 about component analysis, adjustment mechanism integration and sampling program design to solve this problem.

2.2. Vector decomposition
The adjustment analysis of the head thickness and shank length of the screw size can be directly imported into the adjustment guidance system with the length difference measured values $\Delta a$ and $\Delta b$ on the left side of Figure 3, and the maximum eccentricity can be obtained from the analysis of the measurement results in 2.1. $SV_{\text{max}}=V1$ shown on the right.

![Figure 3. Screw spec. measurement side and top view.](image)

The analysis procedure for designing the eccentric component of this research is as described later. The sample measurement program will take three screws in sequence. The first one is the original screw to be adjusted. The maximum eccentric component is $V1$. Add the adjustment level of the die case to the equipment. After measuring $\Delta X$, forging and sampling, the second one to measure its maximum eccentricity $V2'$, the third is to add it to adjust the vertical value of the die case $\Delta Y$ and then sample the third screw to measure the maximum eccentricity $V2$, because $V1$ and $V2$ It can be measured and $\Delta X$ and $\Delta Y$ are known quantities, so the horizontal and vertical components to be adjusted X and Y of the original eccentricity $V1$ on the right side of Figure 3 can be obtained.

In the analytical description of Figure 3, the schematic diagram of the circumscribed circle of the screw head in the top view does not consider the flange outer diameter due to its greater variability and cannot be used as a reference basis for the size. The thickness of the screw flange and the size of its circumscribed circle, so its shape is a free forming zone and is not constrained in the die, and because it is between the head and the shank. It is even more difficult and inaccurate.

2.3. Die case mechanical parts
After the die core of the screw forming machine is installed in the die case and adjusted in position, the screws of the required specifications can be forged in the equipment. The die case adjustment is to obtain the adjustment basis after the workpiece is taken out and measured, and then fine-tune the die case in the equipment, the adjustment of the die core eccentricity of the forming machine used in the domestic industry is mostly judged by manual operation experience. It is necessary to quantify the adjustment relationship and establish a relationship with the measurement results of the optical inspection machine to systematically solve this problem.
The relevant size adjustments of the forming machine have four items, including head thickness, shank length, eccentric X and eccentric Y. Because of the adjustment of head thickness, shank length and eccentric Y, operator only need to understand the conversion relationship between the adjustment mechanism, the adjustment screw rotation angle and the thread pitch can be systematized. What is more complicated is the relationship between the adjustment change of the eccentric X and the change of the eccentric Y component produced by it. As shown in Figure 4, it is a common die case adjustment mechanism, which is commonly referred to as a bull head case in the industry. The principle of operation is to adjust the horizontal eccentricity of rotation to adjust the arc of the die case with the center of rotation. Therefore, when X is adjusted, this legend will also produce a downward shift in the Y direction due to X adjustment. This component can be calculated by similar arcs. When the horizontal eccentric component X needs to be adjusted during adjustment, the system also needs to automatically calculate the compensation Y1 to the original planned eccentric vertical Y component, that is, the adjustment value of the vertical eccentric component must be corrected to Y-Y1.

![Figure 4. Adjust die case trajectory with respect to mechanical component vectors.](image1)

2.4. Sampling process design

In order to solve the problem of analyzing the components of the adjustment die case, this system designed to add the required adjustment procedure and add two adjustment test quantities. According to the design procedure, three screws were picked up and measured in order to obtain the analytical result of the required adjustment component. As shown in Figure 5, the sampling test procedure needs to sample a forged screw before adjusting the machine and measure it by using the optical inspection machine, adjust the die case to a preset known amount ΔX, and then sample to the optical inspection machine measurement, adjust the die case to a preset known amount, then sample the third screw and measure the size with the optical inspection machine, and complete the sampling measurement procedure in sequence.

![Figure 5. Designed sampling process for measurement.](image2)
Figure 6. Forming machine die case adjustment process.

Among them, the Y1 adjustment amount of the above adjustment process is the vertical amount produced by the die case (bull head case) after adjusting the horizontal amount X, as shown in Figure 4, and the adjustment procedure needs to be X adjust first and then merge Y1 to the required Y component becomes the final adjustment Y-Y1.

3. Experimental result

This research has developed a smart die case adjusting guidance system, as shown in Figure 7, where the system functions include optical inspection machine measurement, test sampling, analysis and adjustment of components, and guide die case adjustment user interface. After the designed sampling and die adjustment procedures are embedded, the finished product has to reconfirm with the measurement instrument, and judge whether the required specification is reached or not.

Figure 7. Screw forming die case adjustment guiding system.

This research integrates the adjustment mechanism information of the 40-ton four-punch four-die forming machine of C company, and then imports the information of the optical detector to measure the specification of the screw. After the die adjustment guidance system developed in this research, it is used for the M6 screw for size adjustment verification, as shown in Figure 8. The result of on-machine actual measurement was verified by the adjustment of the die case of the fourth die process. After the screw forged by the forming machine was adjusted twice, the maximum eccentricity value decreased from 0.504mm to 0.121mm in the first adjustment. And the maximum eccentricity reached by the second adjustment is 0.049mm, and the time required for this test procedure from sampling to reaching the size requirement is <20min. For this test, the common eccentricity specification requirements for screws of similar size are 0.15mm~0.3mm, which shows that the system can guide and adjust the machine to obtain quite good results.
6. Conclusion
The results of this paper have been developed through the integration of project image measurement, forming die case adjustment mechanism, corresponding component vector analysis programming. It can provide accurate die case adjustment guidance information and solve it through key vector component analysis technology. To overcome the lack of current measurement methods using in the industry, a set of guidance adjustment system for screw forming machine dies was established by experimental verification, and its effect was verified by domestic actual production equipment and screws. Verifying the program through the actual machine can indeed assist the on-site operators to quickly follow the guidance to complete the equipment punch die case adjustment. This structure can also be extended to other measurement methods to be applied to similar axis-symmetric process equipment such as nut forming machines.

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