Investigations on Reliability of Main Transmission System for High-speed Punch Based on Accelerated Degradation Test

Xinzhou Zhang, *Lan Chen

***Abstract*—A high-speed punch system can be usually divided into nine function subsystems by the main characteristics. Based on the summary and analysis of the reliability accelerated testing technology, the reliability accelerated degradation test is employed to conduct the study of the high-speed punch. Based on the reliability accelerated degradation test, the accelerated analysis of high-speed punch is conducted, which gives the accelerated stress and acceleration factor. Then, the performance degradation model is built based on Brownian motion with drift of the high-speed punch, which is conducted in the condition that the failure mechanisms of the high-speed punch remain unchanged. In order to find the weakness quickly and the reliability growth of the high-speed punch, the reliability test platform of main transmission system is designed, which is the crucial subsystem of the high-speed punch. Based on the basic assumptions of reliability accelerated degradation test, the reliability accelerated degradation test of the high-speed punch is designed after detailed discussions. The experiment of dynamic accuracy of bottom dead center and the amplitude measurement for the high-speed punch is conducted based on the reliability test platform. The obtained results demonstrate that the test platform can be effectively employed to investigate the reliability analysis of high-speed punch.**

***Index Terms*—High-speed punch, Accelerated testing, Reliability test platform, Dynamic measuring, Performance degradation**

I. Introduction

THE high-speed punch is the fundamental equipment of metal forming process. The high-speed punch has the characteristics of high efficiency and wide range, which is employed in the industry of aerospace, automobile manufacturing and chemical metallurgical [1-10]. As the development of related industries, it is an important problem that how to improve the reliability and stability of high-speed punch, which could satisfy the requirement of stamping part. Due to requirement of structure design, the influence of reliability on the dynamic behavior of high-speed punch cannot be neglected. Then, it has serious effect on the machine performance and dynamics stability of mechanism. In addition, the increase of reliability for high-speed punch will improve the machining accuracy of machine. Then, the reliability analysis plays an important role on investigation of high-speed punch. Therefore, it is essential to propose an adapted method to investigate the effects of reliability on dynamic behavior of high-speed punch considering thermal effects.

Over the last few decades, many researchers have studied on the reliability of high-speed punch. Zhao [11] analyzed the working process of the protector shearing fracture and failure mechanism of the protector and characteristics of shear strength of the protector. Xiang [12] set the fault tree with the top event of the presser dashing hand and found the fault occurrence of top event by means of quantitative calculating. Zhang [13] analyzed the failure modes, the failure positions and failure causes for the numerical control punch and found out the weakness of reliability. And the model of the failure probability distribution was obtained by applying total failure time method for the numerical control punch [14]. Su [15] made out signal checking and analysis system based on wavelet analysis to catch the features of mechanical failure of punch machine. Chen [16] designed a reliability test platform for high-speed punch machine clutch brake system, which can be used to find the weakness of clutch brake system. Hu [17] established an elastic dynamic model of high-speed multilink precision press and the model with stiffness of rotation joints is proved more reasonable through related test. Chen et al. [18] proposed a new method to model and describe the dynamic response of a closed high-speed and heavyload press system. The method could effectively describe the dynamic response of mechanism, which could provide assistance of reliability analysis. He [19] also built a contactimpact model that incorporates the IMPACT function and that considers energy loss in the contact process and the method can be effectively predicted for the dynamic response of a multibody mechanical system. Li [20] built a dynamic model of a high-speed overconstrained press machine and developed an efficient approach to perform the dynamic analysis of a planner overconstrained mechanism. There are also some reliability analysis methods [21-26] could be used for the research of high-speed punch. Qian [21] developed an algorithm based

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on Monte Carlo simulation to balance the amount of calculations and the accuracy of the optimal thresholds, which is a very good efficient cost evaluation method. Wen [22] proposed a fault diagnosis strategy of polymerization kettle based on support vector machine (SVM) and it is effective based on the simulation experiments. Li [23-26] did a lot of research work on the reliability degradation. He presented a very effective method to assess the reliability via the degradation data of product, especially for high reliability product, such as high-speed punch. It is helpful to analyze the degradation data of high-speed punch.

However, the reliability technology development of main transmission system of high-speed punch is relatively slow. This dissertation mainly carries on a systemic research on the key technologies and methods of reliability test of main transmission system of high-speed punch, include fault analysis, reliability accelerated degradation test design, reliability test platform development and reliability test.

II. Structural analysis of high-speed punch

A. Working principle of high-speed punch

The working principle of high-speed punch includes two groups has synchronous transmission mechanism, which could improve the stability of mechanism. The motion schematic diagram of high-speed punch is shown in Fig. 1. When the machine operates, the movement of crankshaft is controlled by motor and the pulleys can be defined as the parts of transmission power. During the operation, the big pulley and flywheel can store energy. The crankshaft is connected with slider by the linkages and the circumrotation movement is transformed into beeline movement. The balancing slider and another linkage are installed at the opposite side of crankshaft, which plays an important role in balancing inertial force. The upper die is installed in slider and the lower die is installed in backing plate. The unprocessed sheet is designed between them. The different dies can satisfy the requirement of different stamping process, which is installed in slider. The clutch is installed in crankshaft, which can control the power transmission process. Workbench is used to install dies and frame is the body of the high-speed punch.

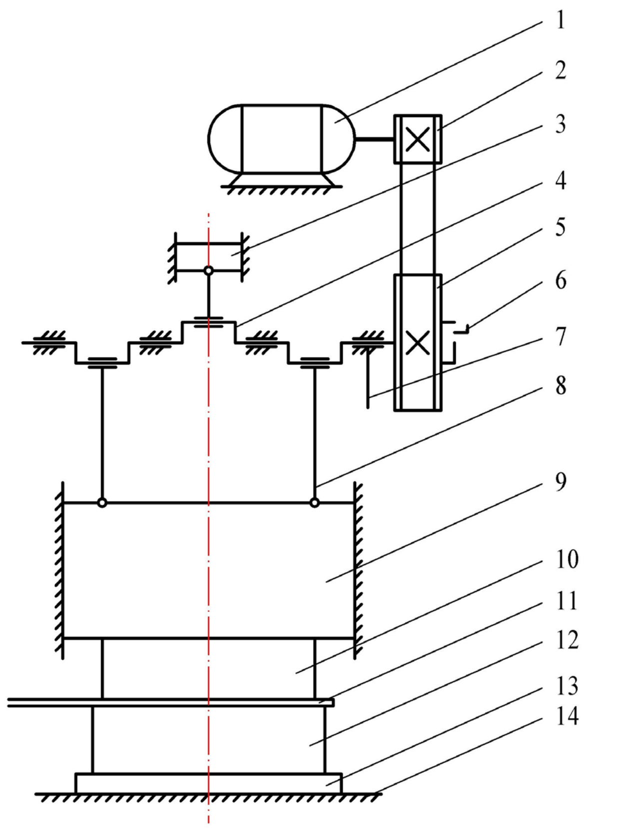

Fig. 1. The motion schematic diagram of high-speed punch
1—Motor 2—Small pulley 3—Balancing slider 4—Crankshaft 5—Big pulley 6—Clutch 7—Frame 8—Linkage 9—Slider 10—Upper die 11—Sheet 12—Lower die 13—Backing plate 14—Workbench

B. Subsystem divided of high-speed punch

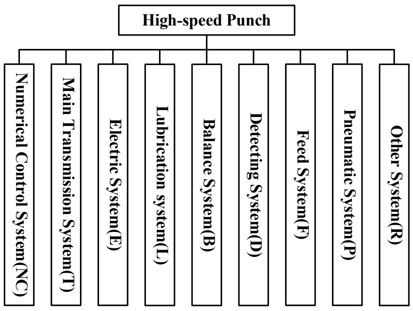

Fig. 2. Subsystems of high-speed punch

High-speed punch is a complex and high automatic system, which is composed by many parts and accessories, and the malfunction of the parts is multifarious. In order to analyze and calculate accurately, it should be divided into several subsystems, which can find the weak link and provide the safeguard easily. Each subsystem can finish a certain function independently, and each subsystem cooperates with each other in order to realize the whole function of the high-speed punch. According to the structure and characteristic of such high-speed punch, it is divided into nine subsystems as followed in Fig. 2.

C. Failure analysis of high-speed punch

Based on the failure data of high-speed punch, the failure positions statistics is shown in Table I. It is described that the Main Transmission System failures (including more failures of the clutch) occur mostly in the malfunctions of high-speed punch, which is about 23.5% of the total ones [21] (We followed the methods of Lan Chen et al. 2016). Including the main failure such as wiring fault, the Electric System failures, components damage and so on, which accounts for 22.9% of the total malfunction. There are also many failures in the Pneumatic System (18.1%) and the Lubrication system (15.2%).

TABLE I
FREQUENCY OF FAILURE POSITIONS

Code	Failure positions	Times	Frequency
T	Main Transmission System	113	0.235
E	Electric System	110	0.229
P	Pneumatic System	87	0.181
L	Lubrication system	73	0.152
D	Detecting System	46	0.096
R	Other System	29	0.060
B	Balance System	17	0.035
F	Feed System	5	0.010
NC	Numerical Control System	1	0.002

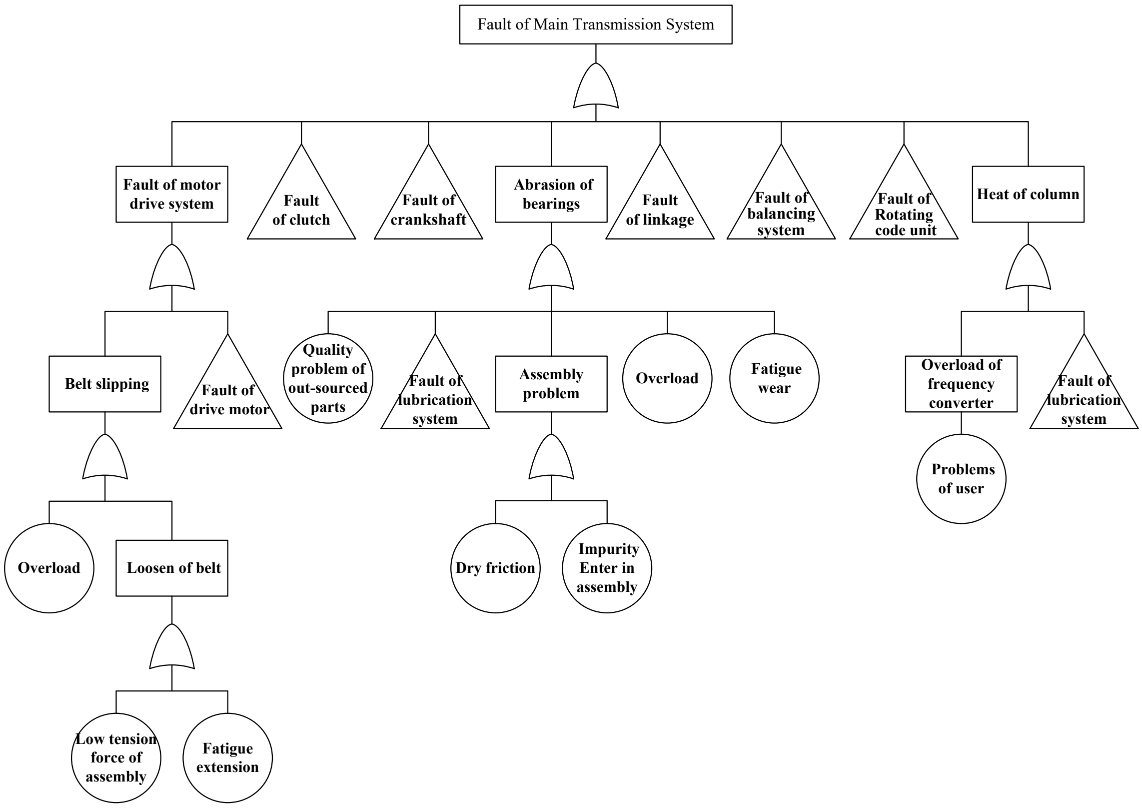

Fig. 3. Fault tree of Main Transmission System

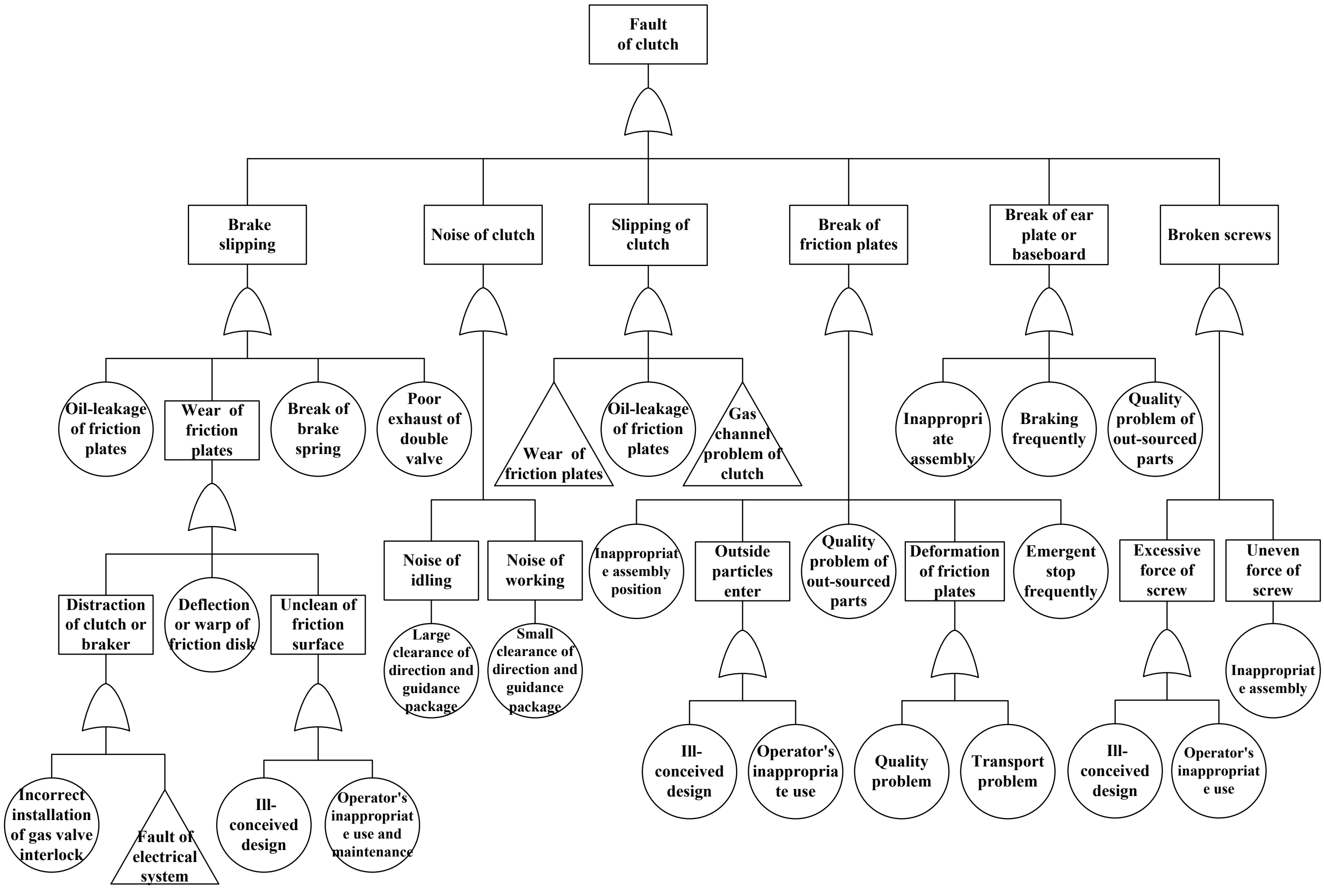

Fig. 4. Fault tree of clutch of Main Transmission System

Because of the high fault frequency of Main Transmission System, it is necessary to make further analysis. The fault tree of Main Transmission System is shown in Fig. 3.

Based on analysis results of the fault tree and the statistical failure data, the following conclusions can be drawn as: (1) In the subsystem of the main transmission system, the clutch failures occur mostly. Then, the validity of judgement for the clutch can work normally plays an important role in determining the reliability of the punch. (2) The fault tree of clutch is shown in Fig. 4, the main failures are break of ear plate or baseboard, fault of direction and guidance package and so on. (3) Fault of balancing system is mainly shown as break of balancing linkage or bearings. For selfmade parts problem, the manufacturer should put forward the corresponding measures to improve the reliability. And for the quality problem of outsourced parts, the test of reliability should be increased.

There are many failures of main transmission system according to the analysis above. Therefore, the main transmission system should be focused on emphatically.

III. Reliability Accelerated Test Technology

A. Accelerated analysis of high-speed punch

The accelerated test can be used to stimulate some specific features within a relatively short time by an appropriate higher stress, and the same features will usually come out spontaneously over a long time in normal operation. It is necessary to analyze whether the accelerated test can be used to research the failure process of high-speed punch. The judgment principles are as follow: 1) The consistency of failure mechanisms: The failure mechanisms remain unchanged under different stress levels and it can be guaranteed by experimental design. 2) The regularity of failure process: There is a certain relationship between the product life and stress, namely the existence of accelerated model. 3) The identity of failure distribution: The product life under different stress levels follows the same distribution.

B. Accelerated accelerating stress

Accelerated stress should be able to stimulate failure or accelerate performance degradation of parts, and cannot change the failure mechanisms in normal use.

The increase of punch load and press speed can check the reliability of the transmission system consists of motor, flywheel, clutch, crankshaft, connecting rod, and the slide block and other components. As the working load and speed increase, the friction torque of the crankshaft gets larger and brings out a large amount of heat, which will cause thermal deformation and transmission precision reduction. In addition, as the increase of punch load and press speed, the inertial load and the vibration stress are also increased. This will stimulate failure or accelerate performance degradation of parts, such as mechanical fatigue, mechanical wear and fracture.

Through the failure analysis of high-speed punch, the punch load and press speed can be selected as accelerated stresses. Considering the fact that the punch load is harder to control, press speed is finally selected as accelerated stress.

C. Reliability accelerated degradation model of high-speed punch

Brownian motion with drift is the most widely used for building performance degradation model based on random process. According to the characteristics of high-speed punch, the geometrical Brownian motion is selected as the performance degradation model for high-speed punch. During the derivation, it is assumed:

(1) The consistency of failure mechanisms: The failure mechanisms remain unchanged under different press speed.

(2) The process of performance degradation has good monotonicity.

(3) The performance degradation should be not outside of the threshold level in accelerated degradation test.

(4) There is a certain statistical correlation between the performance degradation data under different press speed. And the data is normally distributed and the covariance matrix remains unchanged.

(5) Under normal press speed S0 and accelerated press speed $S_1<S_2<\cdots<S_k$, the performance degradation paths follow the model of Brownian motion with drift:

$$Y_l(t)=y_0+d(S_l)t+\sigma_l B(t) \quad l=1,2,\cdots,k \tag{1}$$

where t is the time of degradation, $Y_l(t)$ is the process of degradation, which is Brownian motion with drift, $d(S_l)$ denotes the speed of degradation, y_0 is the initial value of the performance parameter, σ_l is the diffusion coefficient ($\sigma_l>0$), $B(t)$ is standard Brown motion with the average valve is 0 and the variance is the time t ($B(t)$~N(0, t)).

(6) The diffusion coefficient does not change with stress level and time and the diffusion coefficient is constant which means that the failure mechanisms remain unchanged under different stress level ($\sigma_0=\sigma_1=\cdots=\sigma_k$).

(7) Under different press time, the speed of degradation follows general Egrins model:

$$d(S_l)=(A_l/T)\exp\left[B_l/(kT)\right]\cdot S_l^{-C_l} \tag{2}$$

where A_l, B_l, C_l are undetermined constants, which can be estimated by the data of accelerated test, k is Boltzmann constant (k =0.8617×10^{-4}eV/K), T is absolute temperature, S_l is the pressing time.

If we set $Y_l'=Y_l\cdot T$, and take its log, the linearized Eyring model can be got as:

$$\ln Y_l' = a_l + b_l/T + c_l \ln S_l \tag{3}$$

where $a_l=\ln A_l$, $b_l=B_l/k$, $c_l=-C_l$.

Then, the probability density function is:

$$f(t,C_0)=\frac{C_0}{\sigma_l\sqrt{2\pi t}}\exp\left\{-\frac{\left[C_0-Y_l(t)-y_0\right]^2}{2\sigma_l^2 t}\right\} \tag{4}$$

where C_0 is the threshold level of the failure of punch, σ_l is the diffusion coefficient, Y_l is the performance degradation ratio under the stress S_l, y_0 is the initial value of the performance parameter. The reliability function of the punch is:

$$R(t)=\Phi\left[\frac{C_0-y_0-Y_l(t)}{\sigma_l\sqrt{t}}\right]-\exp\left(\frac{2Y_l(t)\cdot(C_0-y_0)}{\sigma_l^2}\right)\Phi\left[-\frac{C_0-y_0+Y_l(t)}{\sigma_l\sqrt{t}}\right] \tag{5}$$

where Φ is the cumulative distribution function which follows the standard normal distribution, $R(t)$ is the reliability evaluation model.

Substituting Eq. (5) into Eq. (4), it is shown with increment as follows:

$$f(\Delta t,\Delta D)=\frac{1}{\sigma_l\sqrt{2\pi\cdot\Delta t}}\exp\left\{-\frac{\left[\Delta D-(A/T)\exp\left[B/(kT)\right]\cdot S_l^{-C_l}\cdot\Delta t\right]^2}{2\sigma_l^2\cdot\Delta t}\right\} \tag{6}$$

N punches are taken to carry out step-stress accelerated degradation test under k stress. S_0 is the normal stress level, $S_1<S_2<\cdots<S_k$ are accelerated stress levels. m_l times are carried out under each accelerated stress level and m times are carried out in all for every punch.

$$\sum_{l=1}^{k} m_l = m \tag{7}$$

There are n punches need to be tested and mn times should be carried out totally. The test time is t_{lij}(l=1,⋯ ,k; i=1,⋯ ,n; j=1,⋯ ,m_l;) every time. So in the test time $\left[0,t_{lim_l}\right]$, the test time is:

$$t_{li1} < \cdots < t_{lim_l} \tag{8}$$

The test value is y_{lij}, the maximum likelihood function of punch is as follows:

$$L \propto \prod_{l=1}^{k}\prod_{i=1}^{n}\prod_{j=1}^{m_l-1}\frac{1}{\sigma_l\sqrt{2\pi\cdot\left(t_{li(j+1)}-t_{lij}\right)}}\exp\left\{-\frac{\left[\left(y_{li(j+1)}-y_{lij}\right)-d\left(S_l\right)\cdot\left(t_{li(j+1)}-t_{lij}\right)\right]^2}{2\sigma_l^2\cdot\left(t_{li(j+1)}-t_{lij}\right)}\right\} \tag{9}$$

Set $x_{lij}=y_{li(j+1)}-y_{lij}$, the interval of time is $\Delta t_{lij}=t_{li(j+1)}-t_{lij}$, substituting the accelerated model and take its log:

$$\ln L \propto -\frac{1}{2}\prod_{l=1}^{k}\prod_{i=1}^{n}\prod_{j=1}^{m_l-1}\left\{\left[\ln\left(2\pi\Delta t_{lij}\right)+\ln\left(\sigma_l^2\right)\right]+\frac{\left[x_{ikj}-\left(A_l/T\right)\exp\left[B_l/\left(kT\right)\right]\cdot S_l^{-C_l}\cdot\Delta t_{lij}\right]^2}{\sigma_l^2\cdot\Delta t_{lij}}\right\} \tag{10}$$

The estimate of the undetermined constant A_l, B_l, C_l: First, the degeneration rate $d(S_l)$ can be got by using least-square fitting method based on the degeneration data under each stress.

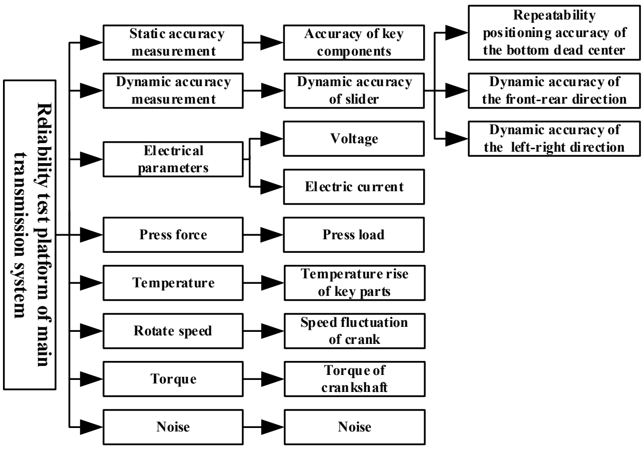

Fig. 5. The test content of main transmission system

Second, the estimate value $\hat{A}_l$, $\hat{B}_l$, $\hat{C}_l$ of the A_l, B_l, C_l can be got through stress level and degeneration rate by fitting analysis under the least-square fitting law.

The estimate of the diffusion coefficient σ_l: taking the partial derivative of σ_l in Eq. (10) and set it zero. The maximum likelihood estimation $\hat{\sigma}_l$ can be got.

The life and reliability of punch under normal stress S_0 can be calculated by the test data under the accelerated stress S_l.

IV. Reliability Test Platform of High-Speed Punch

A. Test content of main transmission system

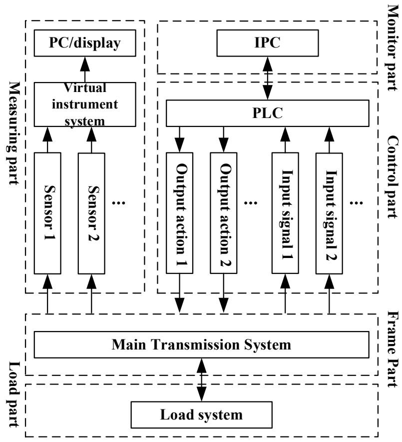

Fig. 6. The sintered samples in orthogonal experiment

The basic requirement of main transmission system includes high repeatability positioning accuracy, functioning smoothly, reliable operation of clutch, longer wearing and so on. The reliability test platform of main transmission system should have the test contents as shown in Fig. 5.

B. Design of reliability test platform

The total structure figure of the system is given in Fig. 6. The total structure is divided into five parts: (1) Frame part, the main transmission system, is the main body for installing test equipment. (2) Load part, the load system, can provide payload. (3) Measuring part will provide many kinds of sensors for measurement. (4) Control part is to control system. (5) Monitor part is monitor host and observes experimental movements.

The total software is divided into seven parts, which includes the bottom dead center measurement system, electrical parameters measurement system, load measurement system, temperature measurement system, rotate speed measurement system, torque measurement system and noise measurement system. The software of measurement system is shown in Fig. 7.

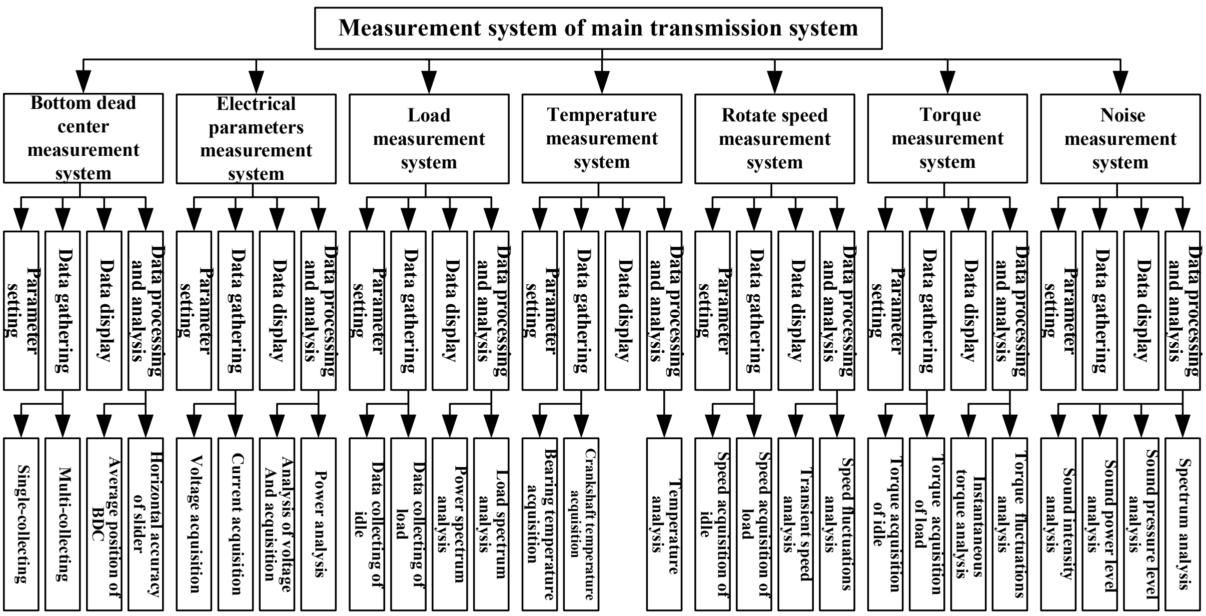

Fig. 7. The software of measurement system

V. Accelerated Degradation Test of High-Speed Punch

A. Design of accelerated degradation test

The fundamental assumption for high-speed punch is as follows:

(1) In the accelerated degradation test, the working stress level and the highest stress level are pre-determined and the highest stress level should not change the failure mechanisms.

(2) The process of performance degradation is monotonically increasing and it is irreversible.

(3) The test ends at the truncation time τ_i, (i=1,··· ,K). Because of the punch is very expensive, the data should be collected as many as possible without breaking the punch.

(4) In the periodical test, the range of test of each group is equal: M. The test time of the ith i(i=1,··· ,K) group is $t_{i1}< t_{i2}<\cdots <t_{iM}=\tau_i$, the interval is determined based on the past project experience.

(5) The performance degradation of the punch before the test is ignored.

According to the analysis above and the practical condition, the test scheme include contents as follows:

Dynamic accuracy test: is to measure the dynamic accuracy of the slider block along X-, Y- and Z-direction

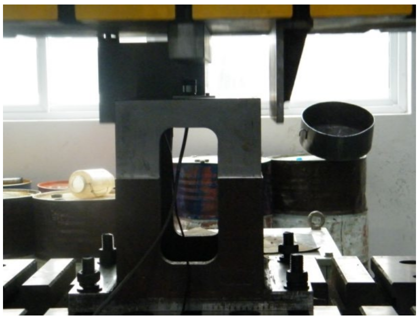

Fig. 8. Dynamic precision test of slider

under different press speed. Measurement sensor: 3 Electric Eddy Transducer (measuring range: 2mm), sensor type: Keyence, controller type: EX-V02, detector: EX-110V, power converter: MS2-H50.

Three displacement sensors are located at a block fixed on the workbench to measure the dynamic accuracy of the slider

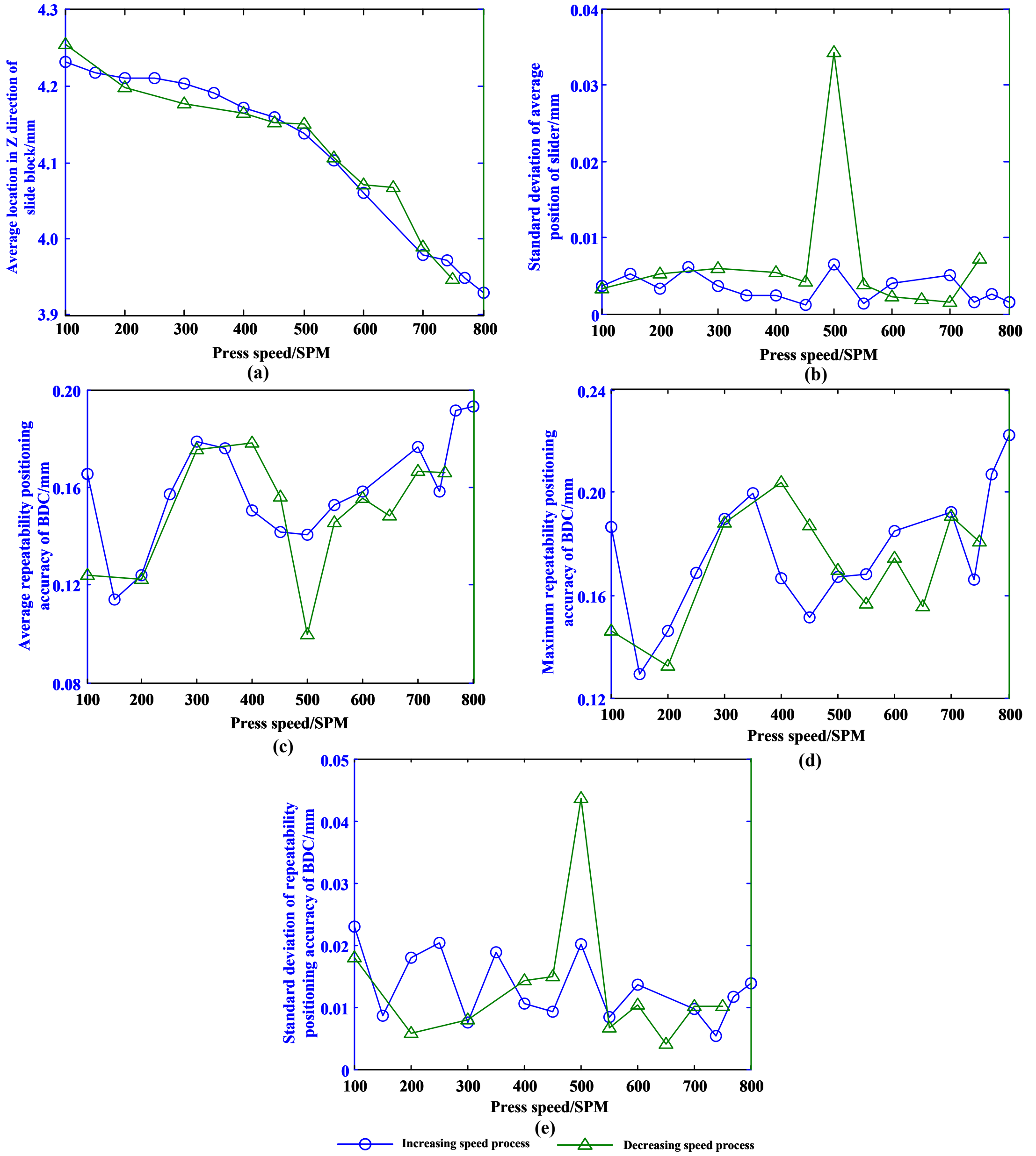

Fig. 9. Dynamic precision test results of slider

block along X-, Y- and Z-direction, respectively.

B. Accelerated degradation test of main transmission system

In idle load cases, the dynamic accuracies of the slider along three directions were measured simultaneously with the punching speed increasing from 100 SPM to 800 SPM gradually [21]. After each speed-up, the signals were acquired while the speed was stabilized, see in Fig. 8. And then, the punching speed decrease from 800 SPM to 100 SPM, the data is collected as the same.

C. Performance degradation analysis of dynamic precision of slider

The dynamic accuracies the bottom dead center (BDC) of the slider is one of the key performance characteristic. The performance degradation analysis of dynamic precision of slider could provide some important information for the reliability growth of the main transmission system.

The test results are drawn in Fig. 9 and many speed values are different in the increasing and decreasing process due to the adjustment problem.

Fig. 9(a) shows that the variations of position are almost the same trend during these two processes. The position of the BDC of slider decreases as the increase of press speed and the greater the press speed is, the larger the change of the curve is. In the increasing press speed process, the aver-age position of the BDC of slider decreases to 0.303 mm and it decreases to 0.281 mm in the decreasing press speed process.

Fig. 9(b) describes that the decrease of standard deviation value in the press speed process with 500 SPM is much larger than others. It shows that the punch of 500 SPM is unstable operation.

As shown in Fig. 9(c), the average repeatability positioning accuracy is difference under different press speed and it changes as a wavy curve. The curve is almost the same in the increase and decrease of press speed process and the maximum value is about 0.19 mm under the press speed of 800 SPM. The minimum value is 0.115 mm under the press speed of 150 SPM in the increasing press speed process and it is 0.10 mm under the press speed of 500 SPM in the decrease of press speed process.

Fig. 9(d) shows the maximum repeatability positioning accuracy and it could happen by chance. The maximum value is about 0.22 mm under the press speed of 800 SPM. Although the curve could not reflect the variation tendency of accuracy under different press speed, it could serve a very significant reference for the analysis of accuracy.

Fig. 9(e) shows the standard deviation of repeatability positioning accuracy. The value is between 0.005-0.02 mm except the maximum value (0.045 mm) under the press speed of 500 SPM. It also shows that the punch of 500 SPM is of unstable operation.

According to the survey data analysis, the position of the BDC of slider decreases as the press speed increasing and the value shows little change for other accuracy. Then, the high-speed punch could satisfy the use requirement under different press speed through the reasonable adjustment. The test results provide some important information for the reliability growth of the high-speed punch.

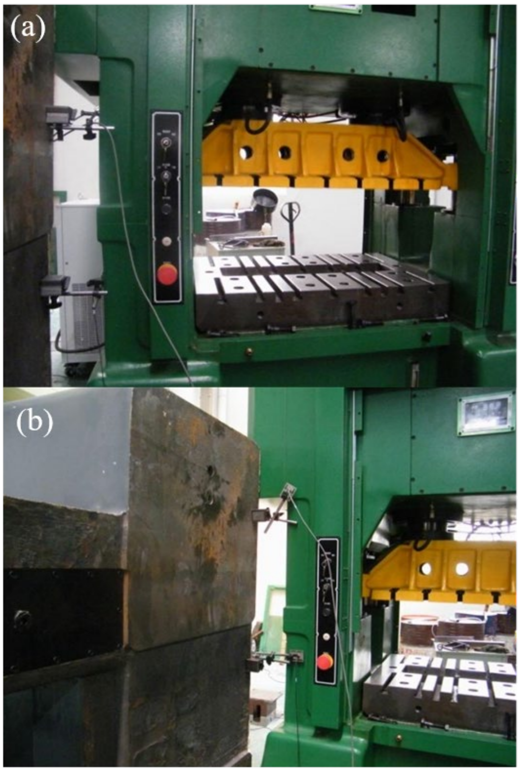

Fig. 10. The amplitude measurement of high-speed punch in (a) X-direction and (b) Y-direction

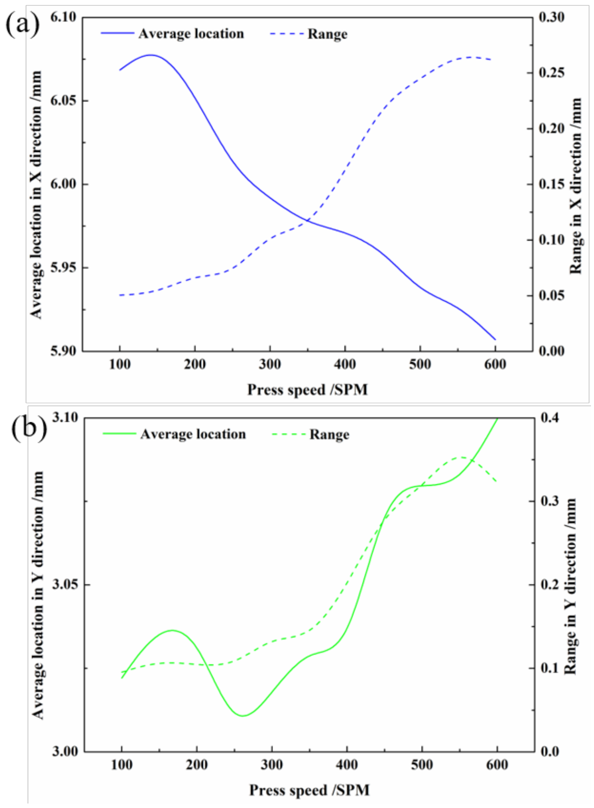

Fig. 11. The positional curve of high-speed punch in (a) X-direction and (b) Y-direction

D. Performance analysis of amplitude of high-speed punch

The amplitude of high-speed punch is also an important performance characteristic which reflects the working reliability. The amplitude is measured in X- and Y- direction as shown in Fig. 10. The senor is same as that in the dynamic accuracy test. A plurality of data is collected in each punching speed state, and 10 results are randomly selected for calculating the average position of the measuring points and the range (the difference between the maximum position and the minimum position).

The measurement results are shown in Fig. 11. It can be seen from the positional curve of the X-direction measuring point in Fig. 11(a), as the punching speed increases, the measuring point position and the sensor spacing gradually decrease, and the maximum value exists at 150 SPM, the difference between the maximum and minimum is 0.18mm. As the punching speed increases, the range value basically increases. There is a peak at 550 SPM, which indicates that the vibration inside the punch is the largest at this speed, the maximum value is 0.267 mm. In general, the machine has a small vibration in the X direction at different punching speeds.

It is noted that with the increase of the punch speed, the distance between the position of the measuring point and the sensor show fluctuations, and there is a maximum value at 600 SPM. As the punching speed increases, the fluctuation range value basically becomes a monotonous increasing trend, and there is a peak at 550 SPM, indicating the vibration inside the punch at this speed, the maximum value is 0.37 mm.

Since the high-speed punch is mounted on the cushion, the vibration of the cushion and the foundation can be caused when the machine is running. Therefore, the overall vibration of the punch is caused by the cushion and the foundation. When the machine is actually working, the mold and the machined parts follow the machine to make the overall vibration, so the vibration at this time will not affect the punching accuracy.

VI. Reliability Growth Analysis

A. Reliability growth planning

According to the characteristics of main transmission system, the reliability growth programming is as shown in Fig. 12.

Procedures are shown as follows [28]:

- (1) The planning procedure of the main transmission system should firstly be made after the theoretical analysis, computer simulation analysis and reliability design.
- (2) To make prototype design of main transmission system with reference to product data, expertise and computer simulation results of similar product in the same category.
- (3) To product the prototype system based on reliability manufacturing and management.
- (4) To make comprehensive experimental scheme, which includes the experiment objective, content, standard, method and evaluation, for reliability growth for the main transmission system.
- (5) To carry out working performance test, which includes geometric accuracy test, static accuracy test and dynamic accuracy test.
- (6) To make early fault test scheme according to the relevant norms and standards for main transmission system and then carry out the test.
- (7) To find the prototype fault and to make reliability growth plan.

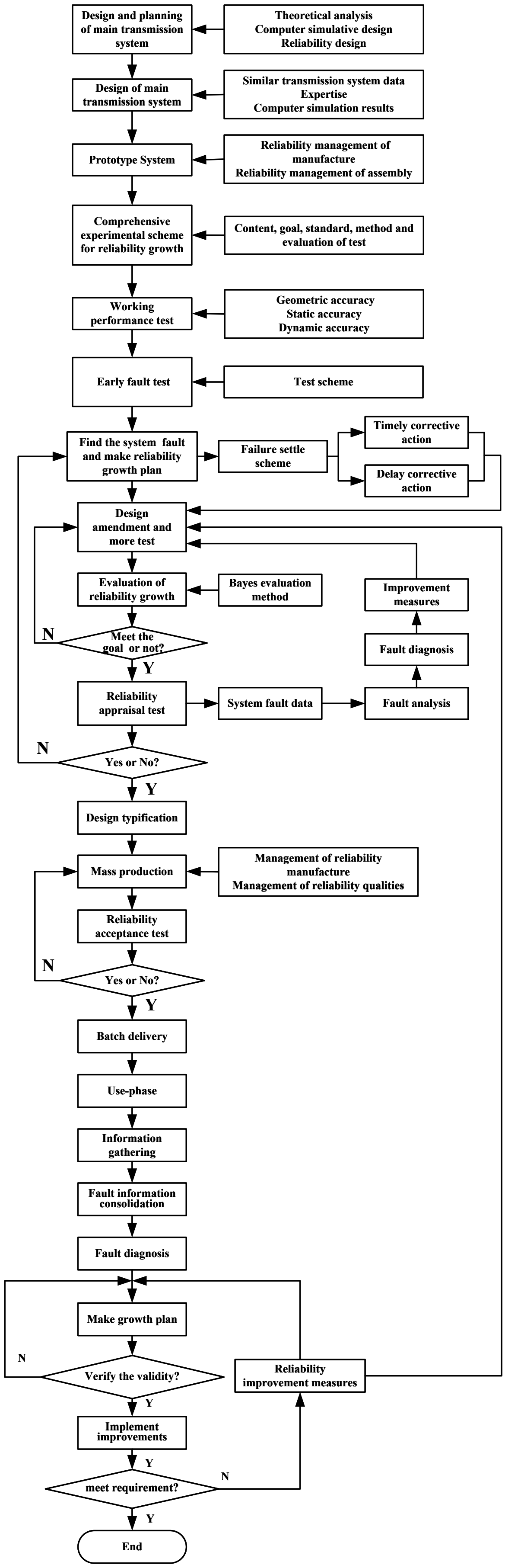

Fig. 12. The procedure of reliability growth for main transmission system

- (8) To make failure settle scheme: take timely corrective action to failures which can be corrected timely and take delay corrective action for others.

- (9) To make design amendment in accordance with the corrective action and then carry out more test.
- (10) To make evaluation of reliability growth based on a small sampling of Bayes method for main transmission system.
- (11) To analyze the evaluation result: if the result achieves the target, then go to next step, otherwise go back to last step.
- (12) To count the failure of reliability appraisal test into fault database. The analysis and fault diagnosis will be made and then draw the relevant improvement measures.
- (13) To make design typification if the reliability appraisal test pass, otherwise go back to step (7).
- (14) To make mass production with reliability manufacture and reliability qualities management.
- (15) To carry out reliability acceptance test: if it passes the test, to deliver into users.
- (16) In use-phase, record the utilization information of main transmission system, such as operating conditions, failure situations and maintenance status.
- (17) To make fault information consolidation of main transmission system.
- (18) To make statistical analysis of fault information and to find weak links of main transmission system.
- (19) To make reliability growth plan based on fault analysis.
- (20) To verify the validity of reliability growth plan: if it works, to implement improvements; or to make reliability growth plan again.
- (21) To examine whether the main transmission system could satisfy the requirement: if it works, it is the end; or to make reliability growth plan again, or go back for more improvement measures.

By the steps, to achieve the significant reliability growth. This method would be effective for the reliability growth of main transmission system.

B. Reliability growth analysis

Based on the reliability growth planning, the reliability growth of the main transmission system is divided into 3 stages (Fig. 13): reliability growth of design phase, reliability growth of manufacturing phase and reliability growth of using phase.

In the design phase: The reliability design requirements of main transmission system are made firstly based on planning requirements. Then, make reliability distribution of components and make reliability analysis and reliability optimization of components with high failure frequency. Finally, make reliability prediction of main transmission system and if the result does not meet the requirement, modify the design.

In the manufacturing phase: To improve the reliability, the early malfunction and weak links of main transmission system should be found and improved design should be made. The early malfunction test is to find potential early malfunction of main transmission system, to check the stability of the main transmission system. So the weak links can be found and some relevant maintenances and corrections can be made for accumulating design experience. While the testing is under way, the systematic failure should be analyzed as soon as possible and some relevant corrections should be made to the prototype punch.

In the using phase: There is always quality feedback and quality improving and the reliability is growing all the time.

Procedures are shown as follows:

- (1) To make record of utilization information of main transmission system, such as on-off time, operating conditions, failure situations and maintenance status.
- (2) To make fault information consolidation of main transmission system.
- (3) To make statistical analysis of fault information and to find weak links of main transmission system.
- (4) To make reliability growth plan based on fault analysis.
- (5) To verify the validity of reliability growth plan: if it works, to implement improvements; or to make reliability growth plan again.
- (6) To examine whether the punch could satisfy the requirement: if it works, it is the end; or to make reliability growth plan again.

VII. CONCLUSIONS

The structure of high-speed punch, the fault tree of main transmission system and the reliability accelerated test technology are studied. The reliability test platform of high-speed punch was built and the accelerated degradation test were carried out to analyze the performance degradation of dynamic precision of slider. The following conclusions can be drawn from this work:

(1) The failure analysis of high-speed punch is analyzed based on the failure and maintenance data and the main transmission system failures occur mostly, which means that it is the weakest link of the high-speed punch. Fault trees of main transmission system and clutch are built to make further analysis.

(2) The reliability accelerated degradation model of high-speed punch is first established in this paper. Brownian motion with drift is used for building performance degradation model and the life and reliability under normal stress could be calculated based on the test data under the accelerated stress by getting the value of some related parameters.

(3) The reliability accelerated test system of main transmission system is built after the reliability accelerated degradation analysis. To validate the rationale of the model, an accelerated degradation test of main transmission system is designed. Test results show that the position of the BDC of slider decreases as the increase of press speed and it is demonstrated reasonable and effectively by the analysis of the reason of the dynamic repeatability precision decline of the BDC, laid the foundation for the comprehensive test of the high-speed punch.

(4) The reliability growth programming of main transmission system is made by 21 steps. The reliability growth is divided into 3 stages: design phase, manufacturing phase and using phase, laid the foundation for the reliability growth of high-speed punch.

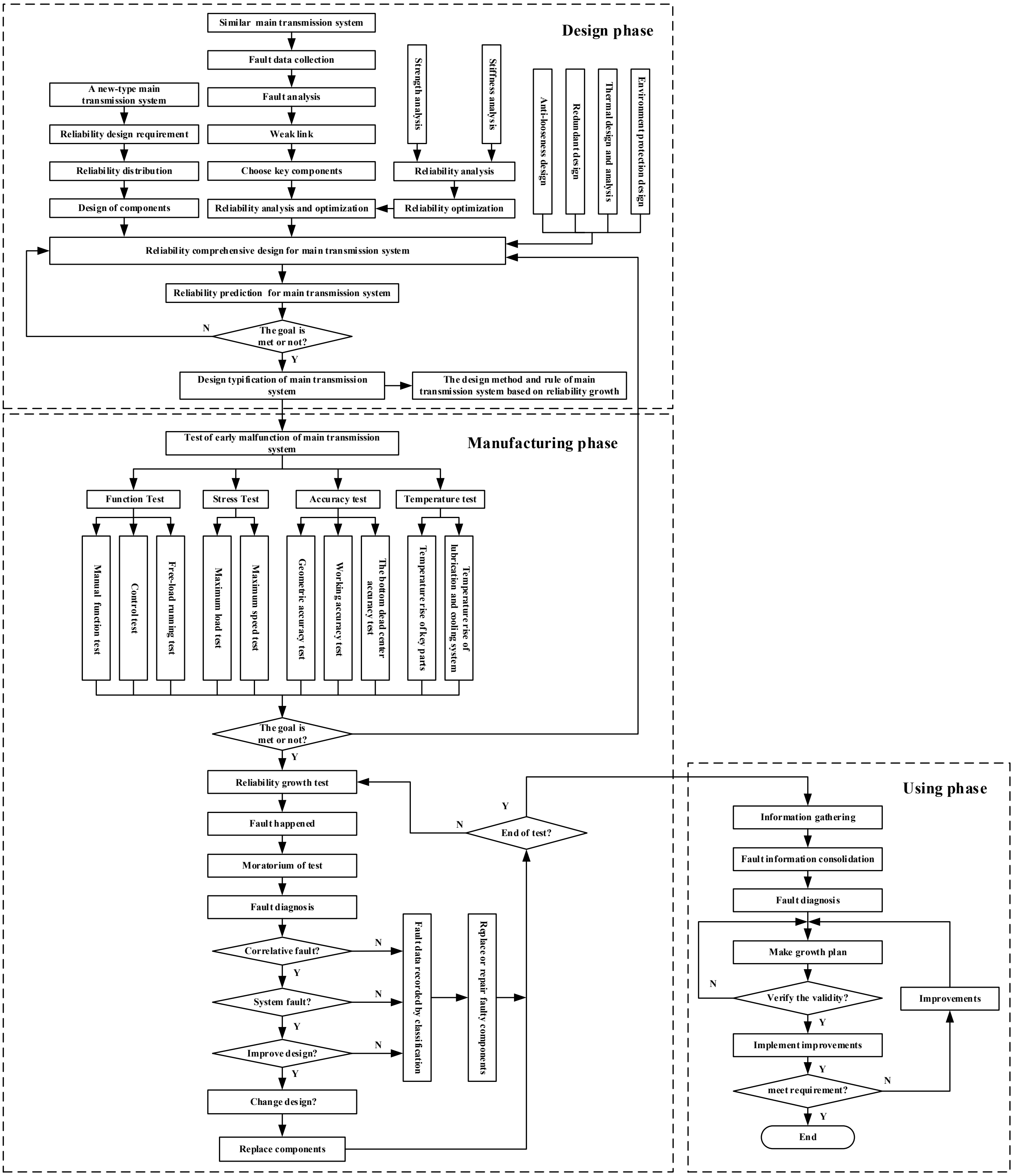

Fig. 13. The reliability growth for main transmission system

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