

# Reliability analysis of crankshaft for high-speed punch based on Monte-Carlo method

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**Abstract.** The crankshaft, which has fateful consequence to the performance and reliability, is a key component of high-speed punch. In manufacturing process, the high reliability value of crankshaft contributes to the increasing of the reliability of the whole punch system. The study builds a reliability analysis model of the crankshaft for punching process under the premise of regarding design parameters as random variables. Monte-Carlo method is employed to make reliability analysis for crankshaft based on ANSYS. The numerical results present that the failure probability of strength and stiffness for crankshaft satisfied the use requirement. The impact of every input variable on reliability are obtained from the sensitivity analysis of status function factors. The design variable D4 and PRXY have the greatest impact on the strength of crankshaft and the design variable YOUNG and L3 have the greatest impact on the stiffness of crankshaft. And the result matches up with the response surface graph. The reliability analysis result provides some useful information for the improvement of the reliability of crankshaft for high-speed punch.

## 1. Introduction

High-speed punch is an efficient, high-precision and high-automation punching machine. It has been widely used in aeronautics and astronautics, automobile, traffic and transportation, metallurgical chemical industries and so on [1-2]. The crankshaft is a key part of main transmission system for high-speed punch and its reliability has great impact on the reliability of high-speed punch.

Modeling and simulation of the crankshaft is obviously not new, as the crankshaft is a very popular mechanism used in many different types of machinery. Zhou [3] constructed a 2-D stress strength interference model, considering the disparity of the load asymmetric factor, to make reliability analysis for diesel engine crankshaft and the analysis result was consistent with the statistical data of actual failure cases. Ye [4-5] analyzed the fatigue reliability of crankshaft for reciprocating pump using the radius vector method and he developed a practical object-oriented application software to make fatigue reliability analysis for improving the design of reciprocating pump. Wang [6] built a quarter finite element model of the entire assembly to make reliability analysis and he got the temperature distribution, thermal deformation and thermal stress distribution of the piston. Taraza [7] developed an algorithm capable to identify faulty cylinders based on the phases of the lowest three harmonic orders of the measured speed. Sun [8] made the fatigue reliability analysis of crankshaft using stochastic response surface method with implicit performance function and some examples were employed to demonstrate the advantages of the proposed method. Wang [9] presented a sensitivity-based algorithm about tool change time and the reliability of the machining process to improve the reliability of both tools and the overall process. Singh [10] provides an optimal model in predicting the



reliability for an automobile crankshaft through the time dependent failure analysis based on three parameter Weibull distribution.

As stated previously, there is few study on reliability analysis of crankshaft for high-speed punch. This work introduces the reliability analysis theory including the basic assumptions of reliability and the reliability calculation method. Then, the reliability analysis model of crankshaft is built in ANSYS and the reliability analysis based on Monte-Carlo method is carried out.

## 2. Reliability analysis theory

### 2.1. Basic assumptions of reliability

Reliability is defined as: the probability that a device will perform its intended function during a specified period of time under stated conditions. The stress-strength interference model is usually employed to make reliability analysis for mechanical components. Stress in the model is typically the factors that has an impact on functionality, such as stress, torque, temperature, vibration, corrosion, and so on. Strength in the model is typically the resistance ability of external loads. The influence in strength is corrosion, temperature, materials performance, quality of machining and external loads. So the definition of reliability is described as: the probability of the strength is greater than the stress.

Some basic assumptions of reliability should be made to analyze the reliability for mechanical products [11]:

- The strength of mechanical components is nonnegative random variable or random process.
- The stress is nonnegative random variable or random process.
- When the strength is greater than the stress, the part is believed to be reliable. Otherwise, the part is believed to be of failure.
- For the stress-strength interference model, the part is of failure only because of the stress.
- The formula for calculating the strength and stress still applies and all quantitative symbols are treated as random variable or random process.

In the stress-strength interference model, the stress and strength are all regarded as random variable or random process, which could reflect the exact thing that the stress and strength are of objective uncertainty, discreteness and time-varying uncertainty. For this reason, the probabilistic method must be used to calculate the reliability of mechanical components.

### 2.2. Reliability calculation method

The reliability could be calculated in the case that the probability density function or joint probability density function of random variable  $X$  is known. That may not always be the case, and the distribution probability is difficult to be determined in the operating condition. There are some approximation methods to calculate the reliability, such as Moment method, Monte-Carlo method, Response Surface method, and so on.

**2.2.1. Moment method.** The moment method mainly includes the first-order second-moment method and the higher order moment method. And the first method is widely used in the actual projects. The basic idea is that Taylor expand the nonlinearity performance function according to the first two moments, and remain the once migration, and then approximately calculate the mean value & standard deviation of performance function to get the reliability.

**2.2.2. Monte-Carlo method.** The basis theory of Monte-Carlo method is large numbers law in probability theory. Monte-Carlo method is one of the most intuitive, accurate and the most efficient for high non-linear problem structural reliability analysis approach. The reliability can be got from statistical analysis of a large random sample.

**2.2.3. Response surface method.** Response surface method is employed to solve the reliability problem of complex mechanical system. The basic idea of this method is to suppose a simple analytic expression between limit state variable and basic variable firstly, then to determine the unknown parameters using interpolation method, and to get the certain analytic expression finally. The

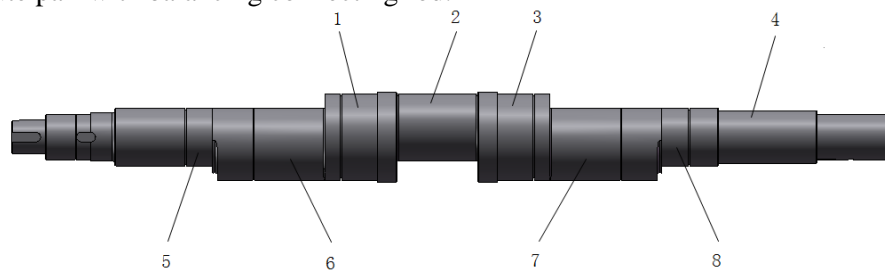
reliability calculation is simplified and the calculation precision could be improved using response surface method. And it can be calculated using finite element analysis program.

### 3. Reliability model of crankshaft

#### 3.1. Structure of crankshaft

The structure sketch of crankshaft is shown as Figure 1 [12-13]. This type of crankshaft is used for 800KN high-speed punch made by a company. The working conditions of the punch are as follows: Nominal Pressure is 800 KN, Nominal Pressure Stroke is 2 mm, Slider Stroke is 30 mm, number of strokes is 600 SPM (Strokes per Minute), the thickness of punched part is 2 mm, the material of crankshaft is 40Cr.

The crankshaft transfer drive torque from the flywheel, which is installed in location 4 with clutch. The four groups of support bearings, which are installed in location 1, 3, 5, 8, form a revolute pair with the punch frame. The two groups of support bearings, which are installed in location 6, 7, form a revolute pair with main connecting rod. One group of support bearing, which is installed in location 2, form a revolute pair with balancing connecting rod.



**Figure1.** Structure sketch of crankshaft

1、3、5、8—Installation locations of support bearing  
2—Installation location of connecting rod bearing of Balancing slider

#### 3.2. Design variables of crankshaft

Design variables of crankshaft fall into three types: material characteristics parameters, load parameters and geometry characteristic parameters. The name of parameter, the distribution type, the variation coefficient and the mean are shown in Table 1. The data is from reference [12-13].

The output variables of crankshaft are *SUBS* and *SUBU*.

$$SUBS = YIES - maxstr \begin{cases} > 0 & \text{reliable state} \\ = 0 & \text{limit state} \\ < 0 & \text{failure state} \end{cases} \quad (1)$$

$$SUBU = U_{\max} - maxu \begin{cases} > 0 & \text{reliable state} \\ = 0 & \text{limit state} \\ < 0 & \text{failure state} \end{cases} \quad (2)$$

Where  $U_{\max}$  is the maximum allowable displacement of crankshaft in vertical direction,  $maxu$  is the maximum allowable displacement of crankshaft in vertical direction.

## 4. Results and discussion

#### 4.1. Histogram of status function

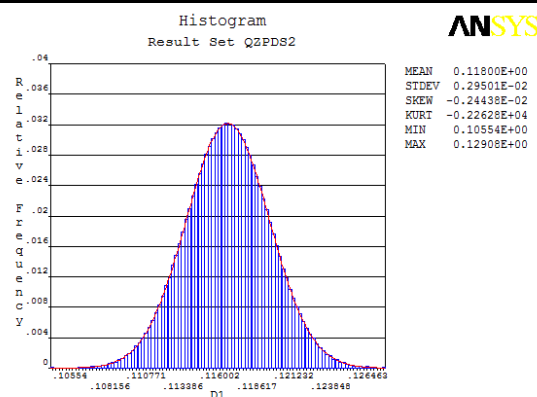
The histogram of design variable *D1* for reliability analysis is shown in Figure 2. As can be seen from the chart, the histogram of design variable approaches the normal distribution probability function curve. The histogram generates a smooth curve without larger gap and the sampling number of simulation is bigger enough to keep the calculating accuracy.

#### 4.2. Graph of response surface

The response surface graph of output status function is shown in Figure 3- Figure 4. Figure 3 shows the impacts of input variable *PRXY* and *D4* on output variable *SUBS*. *SUBS* decreases with the increase of the *D4*, and increases with the increase of *PRXY*. The optimal combination of input variables *PRXY* and *D4* could be found to keep an appropriate *SUBS*.

**Table 1.** The statistical table of input random variable

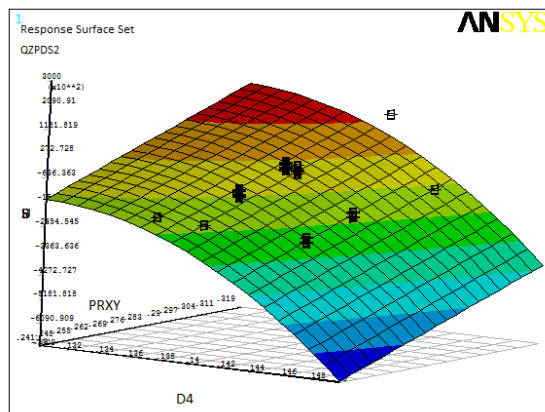
Parameter type	Parameter name	Distribution type	Mean	Variation coefficient	Standard deviation
Material characteristics parameters	Elastic modulus <i>YOUNG</i> /GPa	GAUS	206	0.05	10.3
	Poisson ratio <i>PRXY</i>	GAUS	0.28	0.05	0.014
	Yield strength <i>YIES</i> /MPa	GAUS	345	0.05	17.25
	Density $\rho$ /kg/m <sup>3</sup>	GAUS	7700	0.05	385
Load parameters	Gravitational acceleration <i>g</i>	GAUS	9.8	0.05	0.49
	Load of neck journal of main connecting rod <i>F1</i> /N	GAUS	64897.95	0.07	4542.9
	Load of neck journal of balancing connecting rod <i>F2</i> /N	GAUS	141180	0.07	9882.6
	Diameter of constrained neck journal <i>D1</i> /m	GAUS	0.118	0.025	0.00295
Geometry characteristic parameters	Diameter of neck journal of main connecting rod <i>D2</i> /m	GAUS	0.15	0.025	0.00375
	Diameter of constrained neck journal <i>D3</i> /m	GAUS	0.182	0.025	0.00455
	Diameter of neck journal of balancing connecting rod <i>D4</i> /m	GAUS	0.14	0.025	0.0035
	Length of constrained neck journal <i>L1</i> /m	GAUS	0.055	0.025	0.001375
	Length of neck journal of main connecting rod <i>L2</i> /m	GAUS	0.126	0.025	0.00315
	Length of constrained neck journal <i>L3</i> /m	GAUS	0.074	0.025	0.00185
	Length of neck journal of balancing connecting rod <i>L4</i> /m	GAUS	0.1	0.025	0.0025



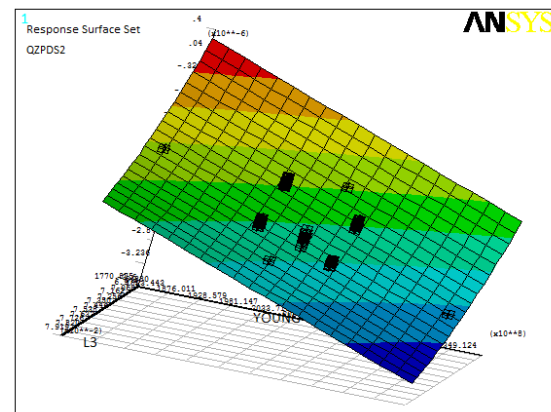
**Figure2.** Histogram of design variable *D1*

Figure 4 shows the impacts of input variable *L3* and *YOUNG* on output variable *SUBU*. *SUBU* decreases with the increase of the *L3*, and decreases with the increase of *YOUNG*. The optimal combination of input variables *L3* and *YOUNG* could be found to keep an appropriate *SUBU*. The

response surface graph can present the impact of multiple variables on output variable and it provides guidance on crankshaft design.



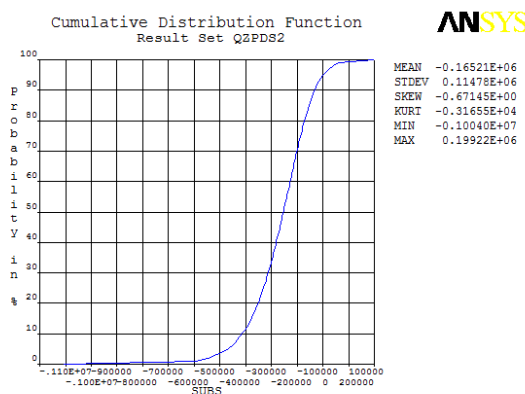
**Figure3.**Response surface graph ofSUBS-PRXY-D4



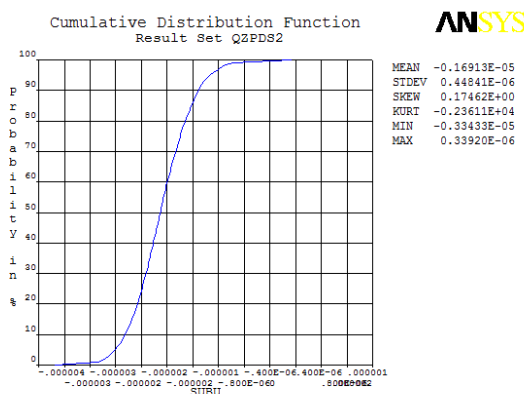
**Figure4.**Response surface graph ofSUBU-L3-YOUNG

#### 4.3. Cumulative distribution function of output status function

The cumulative distribution function of output status function is shown in Figure 5-Figure 6. The value of any point in the distribution function equals to the probability value of data appeared in this point. As shown in Figure 5, the failure probability of strength for crankshaft is probability value of when  $SUBS < 0$ . And the probability value of  $SUBS$  is 0.94863. As shown in Figure 6, the failure probability of stiffness for crankshaft is probability value of when  $SUBU < 0$ . And the probability value of  $SUBU$  is 0.99953.



**Figure5.**Cumulative distribution function of SUBS



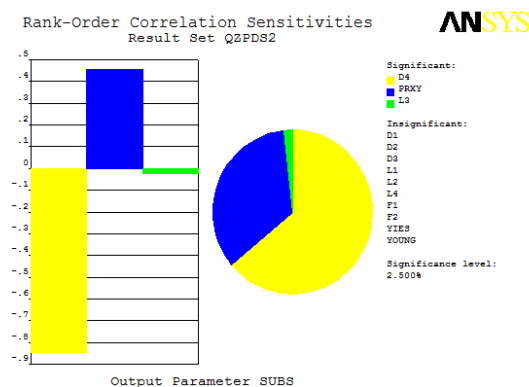
**Figure6.**Cumulative distribution function of SUBU

#### 4.4. Sensitivity analysis of status function factors

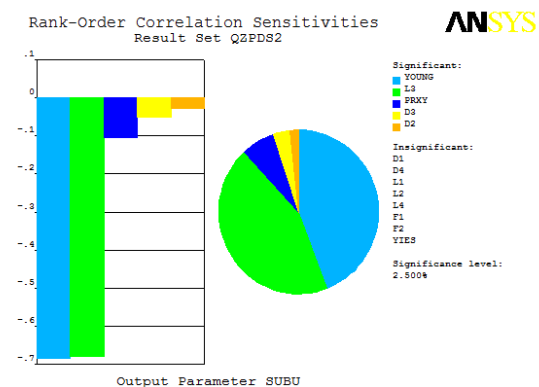
The probability sensitivity reflects the impact of every input variable on reliability. The input variable could be controlled in the design and manufacturing process to get a better product. The sensitivity graph of  $SUBS$  and  $SUBU$  is shown in Figure 7-Figure 8. As shown in Figure 7, the input variable  $D4$  and  $PRXY$  have the greatest impact on  $SUBS$ .  $D4$  is below zero graduation line, which means that  $SUBS$  decreases with the increase of  $D4$ , and  $PRXY$  is above zero graduation line, which means that  $SUBS$  increases with the increase of  $PRXY$ . And it matched up with the response surface graph. As shown in Figure 8, the input variable  $YOUNG$  and  $L3$  have the greatest impact on  $SUBU$ . They are all below zero graduation line and  $SUBU$  decreases with the increase of  $YOUNG$  and  $L3$ .

## 5. Conclusion

This paper studies the reliability of crankshaft for high-speed punch. The reliability analysis theory is introduced, and the basic assumptions of reliability and the reliability calculation method are analyzed. Monte-Carlo method is employed to make reliability analysis for crankshaft based on ANSYS. The numerical results present that the failure probability of strength for crankshaft is 0.94863 and the failure probability of stiffness for crankshaft is 0.99953. The impact of every input variable on reliability are obtained from the sensitivity analysis of status function factors. The input variable *D4* and *PRXY* have the greatest impact on *SUBS* and the input variable *YOUNG* and *L3* have the greatest impact on *SUBU*. This sensitivity analysis result matches up with the response surface graph.



**Figure 7.** Sensitivity graph of *SUBS*



**Figure 8.** Sensitivity graph of *SUBU*

## 6. Acknowledgments

This work is financially supported by Fundamental Re-search Project of the National Natural Science Foundation of China (Grant No. 71601086), the National Natural Science Foundation of Jiangsu Province (Grant No. BK20160485), China Postdoctoral Science Foundation (Grant No. 2015M581748), the Natural Science in Colleges of Jiangsu Province of China (Grant No. 15KJB460005 & 16KJB140002), Jiangsu Planned Projects for Postdoctoral Research Funds (Grant No. 1501102C), Advanced Talent Foundation of Jiangsu University of China (Grant No. 14JDG138 & 15JDG033).

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