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Error allocation for motion mechanism based on the kinematic accuracy reliability

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ABSTRACT: In this paper, we propose a reliability allocation model for motion mechanism. The kinematic accuracy reliability is a function about errors exist in components. In order to make the reliability index can be allocated to the component level. An approach for error allocation is proposed based on the mechanism kinematic reliability. At first, the mechanism motion error functions with original and kinematic errors are given based on the mechanism motion function which is established to illustrate the mechanism motion. Then, we generate the reliability function based on the motion function and the error functions. After that, the cost formula of original errors and kinematic errors is constructed. When establishing the optimal problem of error allocation, the cost function is treated as the objective function, while the reliability function is the constraint. The Genetic algorithm (GA) will be used to obtain the optimal design. According to the machining grade table we choose the most reasonable machining grade and get the final optimal design variables. The Slider-crank mechanism (SCM) application will be selected to illustrate the proposed methodology, and verify its practicability and effectiveness.

1 INTRODUCTION

The motion mechanism is widely used in many engineering applications, where both high accuracy and reliability are required. Kinematic accuracy reliability is an important performance index for evaluating the mechanism quality. Thus, it is critical to conduct mechanism design through the analysis of the mechanism kinematic accuracy. The kinematic accuracy is mainly affected by the original errors and kinematic errors that exist in both the bar length and the joint-gap. The original errors can be treated as random variables, which origin from the process of both manufacturing and assembling. Furthermore, the kinematic errors caused by wearing during usage can also be assumed as random variables. In order to guarantee the stable mechanism performance, the optimal design for kinematic accuracy should be given to meet the requirement of the mechanism reliability in the mechanism design phase. Hence, an approach should be proposed for error design or error allocation.

Many approaches for error allocation have been developed by the literature. Zhao(2001) developed an approach called the Same Error Method that all errors are assumed to be the same. The error allocation model was just for the bar length error allocation based on the accuracy reliability without considering the kinematic error caused by wearing. Then Zhao & Zhao (2002) introduced the Same Influence Method that is similar to the Same Error Method, but is influenced by an extra factor, known as the functional sensitivity coefficient. Both the two methods ignore the accuracy reliability and the kinematic error caused by wearing. Chen & Chen (2002) treated the original errors as design variables, built the optimal error allocation model in which the minimal process cost as objective function, the mechanism kinematic accuracy reliability and the upper and lower bounds of design variables as constraints, while ignoring the kinematic error caused by wearing. Wang (2006) carried out steadiness design of link mechanism based on cost, but the cost function is only about tolerance. Wang (2009) performed an optimal accuracy design for High Speed Press Mechanism at the basis of error analysis without considering the reliability. Wang (2012) built a optimization design model for linkage mechanism based on the reliability of kinematic accuracy only considering motional smoothness, ignoring the kinematic error. Yang & Wen (2014) proposed an improved optimal limit deviation error allocation method by comprehensively considering the cost, size and the assembly performance of engineering. G.Prabhaharan (2004) built a least-cost model for tolerance allocation only considering the error exists in the bar length. S.S. Rao (2005) proposed an interval tolerance allocation method for mechanical assemblies. Kumar A (2010) proposed a framework that overcomes the drawbacks of the traditional tolerance control methods, and reduces subjectivity by using fuzzy set theory and decision support processes, while ignoring the reliability.

Obviously, the above methods have not considered the original and kinematic errors that contribute to the mechanism reliability. In this paper, an optimal design procedure is proposed based on the mechanism kinematic reliability taking into account both the original and kinematic errors.

2 RELIABILITY ANALYSIS OF KINEMATIC ACCURACY FOR MECHANISM

2.1 *Mechanism kinematic accuracy reliability*

Mechanism kinematic reliability is different to structure reliability. The components in mechanical products only meet the strength and stiffness requirement in structure reliability field usually, but also need to meet the required kinematic accuracy in kinematic reliability field. Mechanism kinematic reliability is defined as the ability to complete the specified movement accurately, timely and coordinately in the specified period of used. Mechanism kinematic reliability is classified into two groups: mechanism kinematic accuracy reliability and operating characteristic of power source reliability. In this paper we only study the mechanism kinematic accuracy reliability. It is defined as probability of the displacement, velocity or acceleration of component meets the specified value under the influence of various random factors. We only study the output displacement in this paper and the reliability can be expressed as:

$$R=\phi\left(\frac{\mu_0-\mu}{\sqrt{\sigma_0^2+\sigma^2}}\right) \tag{1}$$

where μ is the mean value of output displacement error, σ^2 is the variance of output displacement error, μ_0 is the specified mean value of output displacement error, σ_0^2 is the specified variance of output displacement error.

We will get the reliability when we get μ and σ^2 if we specify μ_0 and σ_0^2.

If a mechanism consists of components jointed by hinges, Zhao(2002) pointed that for the motion mechanism, the output position is a function of the component parameters, the function is expressed as:

$$Y_0 = f(X_1, X_2, \cdots, X_i) \tag{2}$$

where Y_0 is the output displacement in ideal conditions, X_i is the ith component parameters such as the bar length.

Actually, the error exists in the component length in the manufacturing process, so the output displacement function is expressed as:

$$Y = f(X_1+\Delta X_1, X_2+\Delta X_2, \cdots, X_i+\Delta X_i) \tag{3}$$

where ΔX_i is the ith component length error.

Because of that ΔX_i is far less than X_i, the first order sensitive equation is established on the basis of principle of Taylor series expansion at X_i:

$$Y = f(X_1, X_2, \cdots, X_i) + \sum_{i=1}^{n}\left(\frac{\partial Y}{\partial X_i}\right)\Delta X_i \tag{4}$$

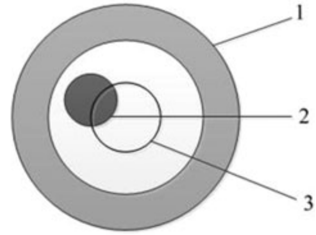

Figure 1. The hinge diagram.

$$\Delta Y = Y - Y_0 = \sum_{i=1}^{n}\left(\frac{\partial Y}{\partial X_i}\right)\Delta X_i \tag{5}$$

where ΔY is the output error, n is the number of components.

We assume that ΔX_i are relatively independent variables, according to the principle of linear superposition of minimum displacement, we can get the equation:

$$\mu = E(\Delta Y) = \sum_{i=1}^{n}\frac{\partial Y}{\partial X_i}E(\Delta X_i) = \sum_{i=1}^{n}\frac{\partial Y}{\partial X_i}\mu_i \tag{6}$$

$$\sigma^2 = D(\Delta Y) = \sum_{i=1}^{n}\left(\frac{\partial Y}{\partial X_i}\right)^2 D(\Delta X_i) = \sum_{i=1}^{n}\left(\frac{\partial Y}{\partial X_i}\right)^2\sigma_i^2 \tag{7}$$

where μ is the mean value of the output displacement error, σ^2 is the variance of the output displacement error, μ_i is the mean value of the ith component length error, σ_i^2 is the variance of the ith component length error.

2.2 *The theory of effective length*

The components in the mechanisms we studied in this paper are jointed by hinges. So, the joint-gap will affect the kinematic accuracy that exists in the junction. The error analysis above ignores the original error exists in the joint-gap. Lee(1991) proposed the "effective length model" that can be used to conduct the output displacement error analysis.

The hinge diagram is shown as Figure 1. The shaft pin moves in the sleeve. The shaft center distributes randomly in the error circle. Radius of the error circle is expressed as:

$$R = \frac{1}{2}(d_1 - d_2) \tag{8}$$

where d_1 and d_2 are the diameter of the sleeve and the shaft pin respectively.

The effective length model is shown as Figure 2, P and C are the center of the sleeve and the shaft pin respectively, the two points do not coincide actually. The effective length L can be expressed as:

$$L = \sqrt{(l+x)^2 + y^2} \tag{9}$$

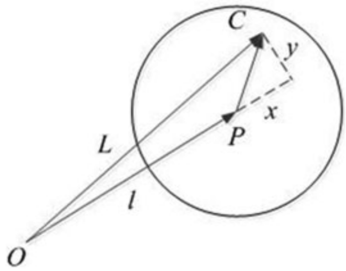

Figure 2. The effective length model.

where l is the real length of component OP, x and y are the center coordinates of the shaft pin.

We assumed that x and y follow standard normal distribution in this paper. According to the probability theory, Luo (2002) has got the formula as:

$$\mu_x = \mu_y = 0 \qquad \sigma_x^2 = \sigma_y^2 = \left(\sigma_R^2 + \mu_R^2\right)\Big/9 \tag{10}$$

where μ_x and μ_y are the mean value of x and y respectively, σ_x^2 and σ_y^2 are the variance of x and y respectively, μ_R and σ_R^2 are the mean value and variance of the joint-gap respectively.

Luo (2002) has derived that the mean value of the output displacement error is equal to equation (6). When the real length l is replaced by the effective length L, according to equation (7), the mean value and variance of the output displacement error are expressed as:

$$\mu = \sum_{i=1}^{n} \frac{\partial Y}{\partial X_i}\mu_i \qquad \sigma^2 = \sum_{i=1}^{n}\left(\frac{\partial Y}{\partial X_i}\right)^2\left(\sigma_i^2 + \frac{\sigma_{Ri}^2 + \mu_{Ri}^2}{9}\right) \tag{11}$$

where μ_{Ri} and σ_{Ri}^2 are the mean value and variance of the ith joint-gap.

2.3 *The reliability model considering kinematic error caused by wearing*

The above error analysis is based on the original errors that exist in both the bar length and the joint-gap. The shaft pin moves in the sleeve, so the wear behavior is a universal phenomenon between hinges. The joint-gap will increase with the wearing. Zhao(2011) pointed that the wearing is the mainly factor that affects the kinematic accuracy. It is studied that the increased joint-gap is equal to the worn loss, it is shown as the following formula:

$$\Delta_R' = \Delta_R + \Delta_q \tag{12}$$

where Δ_R' is the final joint-gap, Δ_R is the original joint-gap, Δ_q is the worn loss.

We assume that the worn loss is a random variable, then can get the following equation:

$$\mu_R' = E(\Delta_R') = E(\Delta_R) + E(\Delta_q) = \mu_R + \mu_q \qquad \sigma_R'^2 = D(\Delta_R') = D(\Delta_R) + D(\Delta_q) = \sigma_R^2 + \sigma_q^2 \tag{13}$$

where μ_R' and $\sigma_R'^2$ are respectively the mean value and variance of the final joint-gap, μ_R and σ_R^2 are respectively the mean value and variance of the original joint-gap, μ_q and σ_q^2 are respectively the mean value and variance of the worn loss.

According to equation (11) we can get the mean value and variance of the output error:

$$\mu = \sum_{i=1}^{n} \frac{\partial Y}{\partial X_i}\mu_i \qquad \sigma^2 = \sum_{i=1}^{n}\left(\frac{\partial Y}{\partial X_i}\right)^2\left(\sigma_i^2 + \frac{\sigma_{Ri}^2 + \sigma_q^2 + \left(\mu_{Ri} + \mu_q\right)^2}{9}\right) \tag{14}$$

The existed researches have show that the wear behavior has three periods, the grinding-in period, the steady wear stage and the acceleration wear period. We take the steady wear stage for example, the wear rate is a constant value, so the worn loss can be expressed as:

$$q = vt \tag{15}$$

where q is the worn loss, v is the wear rate, t is the working time.

Since wear rate is relevant to some random factors such as load, temperature and use condition, wear rate is a random variable.

$$\mu_q = \mu_v t \qquad \sigma_q^2 = \sigma_v^2 t^2 \tag{16}$$

According to equation(14) and equation(16), we can get:

$$\mu = \sum_{i=1}^{n} \frac{\partial Y}{\partial X_i}\mu_i \qquad \sigma^2 = \sum_{i=1}^{n}\left(\frac{\partial Y}{\partial X_i}\right)^2\left(\sigma_i^2 + \frac{\sigma_{Ri}^2 + \sigma_v^2 t^2 + \left(\mu_{Ri} + \mu_v t\right)^2}{9}\right) \tag{17}$$

where μ_v and σ_v^2 are the wear rate mean value and variance respectively.

Through substituting equation (17) into equation (1), we can get the reliability.

3 THE APPROACH FOR ALLOCATION

The kinematic accuracy reliability is a function about errors. So, the reliability allocation can be treated as error allocation. Errors are mainly reflected in accuracy and tolerance which are related to cost, So, cost function about errors should be established.

3.1 *The accuracy cost function*

It is known that cost is related to the machining accuracy. It will cost more if we require a higher accuracy. The smaller variance, the higher accuracy. Chen (2002) established the cost-accuracy function:

$$G(\sigma_i) = C_i\left(\sigma_i - \sigma_i'\right)^2 + D_i \tag{18}$$

where C_i is a modification coefficient of machining grade, σ_i is the machining accuracy of ith component, σ_i' is the lowest machining accuracy of ith component, D_i is basic cost.

So, the total accuracy cost function is expressed as:

$$G(\sigma) = \sum_{i=1}^{m} G(\sigma_i) \tag{19}$$

where m is the number of error variance we considered.

We can adjust the parameters in equation (18) to make the cost curve is consistent with actual situation as much as possible.

3.2 *The tolerance cost function*

Cost is also related to the component tolerance, but it is hard to build a cost function about tolerance. According to the statistics of experimental data, the cost decrease in the negative exponent form with the tolerance increasing. The Dieter curve is a classical curve about cost-tolerance in recent researches. Wang(2006) established the cost-tolerance function through the Dieter curve. It can be expressed as a exponential function:

$$C(T_i) = a_i e^{-b_i T_i} \tag{20}$$

where T_i is the tolerance, a and b are curve-fitting parameters that greater than 0.

According to the "3σ" principle in mechanical design, the tolerance of the component size is expressed as:

$$T_{ci} = 6\sigma_i \tag{21}$$

where T_{ci} is the tolerance of the ith component size.

We assume that the joint-gap deviation is symmetric, and the tolerance of the ith joint-gap is expressed as:

$$T_{Ri} = 2\mu_{Ri} \tag{22}$$

where T_{Ri} is the tolerance of the ith joint-gap

So, the total tolerance cost function is expressed as:

$$C(T) = \sum_{i=1}^{n} C(T_i) \tag{23}$$

where n is the number of tolerance we considered.

3.3 *The optimal model for allocation*

The errors of length and joint-gap can affect mechanism kinematic accuracy. In order to improve the kinematic accuracy, these errors should be controlled strictly when we design a mechanism. But, it will cost more if these errors are controlled strictly. In order to solve this problem, we treat the reliability function about errors and joint-gap as the constraint with the goal that the cost function should be minimum. The optimal model is expressed as:

$$\begin{aligned}
&\min W = G(\sigma) + C(T) \\
&s.t. \frac{\mu_0 - \mu}{\sqrt{\sigma_0^2 + \sigma^2}} \geq \phi^{-1}(R_0) \\
&0 < \sigma_i \leq \sigma_i' \\
&\mu_R > 0 \\
&\mu_q > 0 \\
&\sigma_q > 0
\end{aligned} \tag{24}$$

where R_0 is the required reliability.

3.4 *The allocation process*

Before the mechanism design, the required reliability R_0 with the working time t, and the allowed output displacement error characteristic value (μ_0, σ_0) should be specified. The wear rate characteristic value (μ_v, σ_v) will be given when the component material has been determined according to the mechanism kinematic law. It is assumed that the component dimension deviation is symmetric, so the component length error mean value is 0. The component length error characteristic value ($0,\sigma_i$) and joint-gap characteristic value (μ_{Ri}, σ_{Ri}) are design variables.

The allocation process can be mainly divided into three steps as following:

Step 1: We assume that the initial wear rate characteristic value (μ_v,σ_v) can be obtained before reliability allocation, and we should verify whether the wear rate meets the required reliability in the working time or not according to equation (17) and equation (1), under the condition that all error characteristic values are 0. If it does not meet the required reliability, we need choose a material with good wear resistance.

Step 2: Use Genetic algorithm (GA) to solve the optimal problem (24). Then we will get the design variables.

Step 3: When the tolerance T_{ci} of the component size is obtained based on equation (21), then we should judge whether the ith component tolerance can be machining or not according to the Table 1.

Wu (1990) derived the mathematical relationship between k and D.
when $D \leq 500$ mm:

$$k = 0.45\sqrt[3]{D} + 0.001D\,(\mu m) \tag{25}$$

Table 1. The tolerance in different machining grade (μm).

Tolerance grade	IT5	IT6	IT7	IT8	IT9	IT10	IT11	IT12	IT13	IT14	IT15	IT16	IT17	IT18
$D \leq 500$	$7k$	$10k$	$16k$	$25k$	$40k$	$64k$	$100k$	$160k$	$250k$	$400k$	$640k$	$1000k$	$1600k$	$2500k$
$500 < D \leq 3150$	$7k$	$10k$	$16k$	$25k$	$40k$	$64k$	$100k$	$160k$	$250k$	$400k$	$640k$	$1000k$	$1600k$	$2500k$

when 500 mm < D ≤ 3150 mm:

$$k = 0.004D + 2.1(\mu m) \tag{26}$$

where D is the component length.

If the tolerance can be machining we should choose a reasonable machining grade, it can be expressed as:

$$h = \left[\frac{T_{ci}}{k}\right] \tag{27}$$

where h is a maxint among these values (7, 10, 16, 25, 40, 64, 100, $\cdots$, 1000, 1600, 2500) that smaller than T_{ci}/k.

Then the final optimal tolerance is expressed as:

$$T_{ci}^{'} = hk \tag{28}$$

If the tolerance is beyond the highest machining accuracy grade we should choose a material with good wear resistance; if the tolerance is beyond the lowest machining accuracy grade we should choose the lowest machining accuracy grade in order to cost less.

4 CASE STUDY

The slider crank mechanism(SCM) is a common device that widely used in various mechanical products. To show the effective application of the proposed error allocation model, it has been developed for this specific case.

As the Figure 3 shows, r is the length of the crank OA, l is the length of the connecting rod AB, α is the angle crank OA rotated. Y represents the output displacement. If $r = 20$ cm, $l = 40$ cm, the rotation angle $\alpha = 90°$ after it worked 20 kh, the required reliability of SCM is 0.942 ($R_0 = 0.942$). The error characteristic value of output displacement Y is specified as $(\mu_0, \sigma_0) = (0.95, 0.01)$(cm), We take the steady wear stage for example the wear rate characteristic value of the material we selected is specified as (μ_v, σ_v) = (0.06,0.0033) (cm/kh) at O and A point. We assume that the joint-gap characteristic values of O and A are the same expressed as (μ_R, σ_R), the joint-gap of B can be neglected.

Step 1: We assume that all error characteristic values are 0 in equation (17); according to equation (17), we can get:

$$\begin{aligned} &\mu=0 \\ &\sigma^2 = 0.2675 \end{aligned} \tag{29}$$

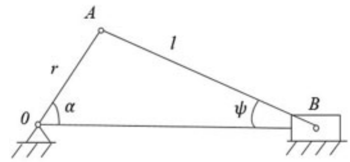

Figure 3. The slider crank mechanism.

According to equation (1), the reliability is

$$R=\phi\left(\frac{0.95-0}{\sqrt{0.01^2+0.2675}}\right)=0.97 \tag{30}$$

Obviously, $R > R_0$, it indicates that we can conduct allocation.

Step 2: If $C_r = C_O = C_A = 9000$, $C_l = 10^5 \sigma_i' = D_i = 1$ in equation(18), according to equation(18) and (19), the total accuracy cost function is expressed as:

$$\begin{aligned} G(\sigma)=&9\times10^3\times(\sigma_r-1)^2+10^5\times(\sigma_l-1)^2 \\ &+2\times9\times10^3\times(\sigma_R-1)^2+4 \end{aligned} \tag{31}$$

If $a_r = 9000$, $a_l = 10^5$, $a_O = a_A = 1.5 \times 10^5$, $b_i = 1$ in equation (20), according to equation (20) (21), (22) and (23), the total tolerance cost function is expressed as:

$$\begin{aligned} C(T)=&9\times10^3\times e^{-6\sigma_r}+10^5\times e^{-6\sigma_l} \\ &+2\times1.5\times10^5\times e^{-2\mu_R} \end{aligned} \tag{32}$$

The total cost function is expressed as:

$$\begin{aligned} W=&9\times10^3\times(\sigma_r-1)^2+10^5\times(\sigma_l-1)^2 \\ &+2\times9\times10^3\times(\sigma_R-1)^2+4 \\ &+9\times10^3\times e^{-6\sigma_r}+10^5\times e^{-6\sigma_l} \\ &+2\times1.5\times10^5\times e^{-2\mu_R} \end{aligned} \tag{33}$$

The mechanism motion function is expressed as

$$Y = r\cos\alpha + \sqrt{l^2 - r^2\sin^2\alpha} \tag{34}$$

According to the equation (5), The error function about Y is expressed as:

$$\Delta Y = \frac{\partial Y}{\partial r}\Delta r + \frac{\partial Y}{\partial l}\Delta l + \frac{\partial Y}{\partial \alpha}\Delta\alpha \tag{35}$$

We assume that α is an ideal value without error, then:

$$\Delta Y = \frac{\partial Y}{\partial r}\Delta r + \frac{\partial Y}{\partial l}\Delta l \tag{36}$$

Table 2. The optimal results (cm).

Design variable	Optimal result/cm
σ_r	0.071
σ_l	0.139
μ_R	0.149
σ_R	0.081

$$\frac{\partial Y}{\partial r} = \cos\alpha - \frac{r\sin^2\alpha}{\sqrt{l^2 - r^2\sin^2\alpha}} \tag{37}$$

$$\frac{\partial Y}{\partial l} = \frac{l}{\sqrt{l^2 - r^2\sin^2\alpha}} \tag{38}$$

When $\alpha = 90°$, $r = 20$ cm, $l = 40$ cm according to the equation (37) and (38), so:

$$\frac{\partial Y}{\partial r} = \frac{1}{\sqrt{3}}, \frac{\partial Y}{\partial l} = \frac{2}{\sqrt{3}} \tag{39}$$

According to equation (17), the mean value and variance of the output error are expressed as:

$$\begin{aligned} &\mu = 0 \\ &\sigma^2 = \frac{1}{3}\left(\sigma_r^2 + \frac{\sigma_R^2 + (0.0033\times 20)^2 + (\mu_R + 0.06\times 20)^2}{9}\right) \\ &+\frac{4}{3}\left(\sigma_l^2 + \frac{\sigma_R^2 + (0.0033\times 20)^2 + (\mu_R + 0.06\times 20)^2}{9}\right) \end{aligned} \tag{40}$$

Referring to the table of standard normal distribution, the reliability coefficient is expressed as:

$$\phi^{-1}(R_0) = \phi^{-1}(0.942) = 1.57 \tag{41}$$

According to equation (24), the optimal allocation model is expressed as:

$$\begin{aligned} &s.t.\frac{0.95}{\sqrt{0.01^2 + \sigma^2}} \geq 1.57 \\ &0 < \sigma_r \leq 1, 0 < \sigma_l \leq 1, 0 < \sigma_R \leq 1 \\ &\mu_R > 0, \mu_q > 0, \sigma_q > 0 \end{aligned} \tag{42}$$

where W is expressed as equation (33), σ^2 is expressed as equation (40).

By using Genetic algorithm (GA), the optimal results are shown in Table 2.

Stept 3:

According to equation (21) we can get that:

$$\begin{aligned} T_r &= 6\sigma_r = 0.426cm \\ T_l &= 6\sigma_l = 0.834cm \end{aligned} \tag{43}$$

where T_r and T_l are the optimal tolerance of crank OA and connecting rod AB we get respectively.

According to equation (25) we can get:

$$\begin{aligned} k_r &= 0.45\sqrt[3]{200} + 0.001\times 200 = 2.83(\mu m) \\ k_l &= 0.45\sqrt[3]{400} + 0.001\times 400 = 3.71(\mu m) \end{aligned} \tag{44}$$

Table 3. The final optimal results.

Design variable	Optimal result/cm
σ_r'	0.047
σ_l'	0.099
μ_R	0.149
σ_R	0.081

According to equation (27)

$$\begin{aligned} h_r &= \left[\frac{T_r}{k_r}\right] = 1000 \\ h_l &= \left[\frac{T_l}{k_l}\right] = 1600 \end{aligned} \tag{45}$$

According to equation (28), the final optimal tolerance is expressed as:

$$\begin{aligned} T_r' &= h_r k_r = 1000\times 2.83\mu m = 0.283cm \\ T_l' &= h_l k_l = 1600\times 3.71\mu m = 0.5936cm \end{aligned} \tag{46}$$

where T_r' and T_l' are the final optimal tolerance of OA and AB respectively.

The final optimal results are shown in Table 3.

The component dimension deviation is symmetric, so the deviation is:

$$\Delta r = \frac{1}{2}T_r' = 0.1415, \ \Delta l = \frac{1}{2}T_l' = 0.2968 \tag{47}$$

Finally, when the we conduct the SCM accuracy design, the component parameters must meet the values as following:

$r = 20^{+0.1415}_{-0.1415}$ cm, $l = 40^{+0.2968}_{-0.2968}$ cm, the joint-gap characteristic value is (0.149,0.081) referring to Table 2.

5 CONCLUSIONS

This work shows a general process of how to select the most reasonable machining grade and get the component tolerance. The reliability allocation can be regarded as error allocation by establishing the kinematic accuracy reliability function about errors considering the wear relevant to time. So, the reliability index can be design to the component level embodied in the tolerance of component size and joint-gap. We treat the cost function about the design variables we established as objective function and the reliability function as constraint. The optimal result can help the developer choose a reasonable tolerance.

Finally, the proposed model has been applied to SCM and get a reasonable result proving its effectiveness. Further research has to be done to develop a general allocation model considering established a cost function about wear characteristic value that can help developer determine the component material.

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