Optimal Strategy for Producing a High Quality Relay in a Machining-assembly Production System Applied a Corrective Assembly Approach

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Abstract

In this paper, we propose an optimal strategy to maximize a production rate of high quality relay that satisfies a predetermined assembly tolerance in a relay machining-assembly production system applied a corrective assembly approach. In this strategy, an optimal adjusting machine is selected online according to a selection-probability of each adjusting machine. At first, the strategy is formulated. Next, the optimality of the strategy and effects of some parameters are presented.

1 Introduction

A relay is one of important electric devises, and a higher quality relay has been required. A relay is usually composed of two main parts, and a tight assembly tolerance is required to satisfy the high quality. However, machining errors occur when assembly parts are produced, so a corrective assembly approach[1] is applied to a machining-assembly production system. In the corrective assembly approach, a pair of assembly parts is selected in a production line, and is assembled after one of the parts is reprocessed by a selected adjusting machine. However, as the required assembly tolerance becomes tighter, the production rate of high quality relay drops because a measurement error and a reprocessing error occur in a measuring process and an adjusting process, respectively. These errors cause an erroneous selection of the adjusting machine and an unpredictable assembly error.

In this paper, we propose an optimal strategy to maximize the production rate of high quality relay that satisfies a predetermined assembly tolerance in a relay machining-assembly production system applied the corrective assembly approach. At first, the strategy is formulated. Next, the optimality of the strategy, and effects of a predetermined assembly tolerance and a reprocessing accuracy on the maximum production rate are presented.

2 Production system and corrective assembly approach

A relay is generally composed of two main assembly parts; armature (part A) and base (part B). Parts A and B have design dimensions L_A and L_B, respectively. An assembly dimension L_B-L_A determines the quality of relay, and a predetermined assembly tolerance is set. A relay production system is composed of machining stages S_A and S_B, measuring stages S_{MA} and S_{MB}, reprocessing stage S_C, and assembly stage S_D. In stage S_C, *NK* adjusting machines with a different adjustment size are installed to adjust the part A so as to satisfy the predetermined assembly tolerance.

In the system, machining errors ΔW_A and ΔW_B occur in stages S_A and S_B in producing parts A and B, and measurement errors ΔM_A and ΔM_B occur in stages S_{MA} and S_{MB} in measuring the machining errors of parts A and B, respectively. As a result, when a pair of parts A and B is selected in a production line to be assembled, a true assembly error $\Delta Y=\{(L_B+\Delta W_B)-(L_A+\Delta W_A)\}-(L_B-L_A)=\Delta W_B-\Delta W_A$, and an estimated assembly error $\Delta Y^*=\{(L_B+\Delta W_B+\Delta M_B)-(L_A+\Delta W_A+\Delta M_A)\}-(L_B-L_A)=(\Delta W_B-\Delta W_A)+(\Delta M_B-\Delta M_A)$. Furthermore, a reprocessing error occurs in stage S_C in adjusting the part A. Consequently, when an adjusting machine M_i (i=1,2,…,*NK*) is selected, a true reprocessing assembly error ΔY^+ after reprocessing is given by Eq. (1).

$$\Delta Y^+=\{(L_B+\Delta W_B)-(L_A+\Delta W_A+E_i+\Delta E_i)\}-(L_B-L_A)=\Delta W_B-(\Delta W_A+E_i+\Delta E_i), \quad (1)$$

where E_i and ΔE_i are the adjustment size and a reprocessing error of M_i. If adjusting is not necessary, $E_i=\Delta E_i=0$. In this process, the true assembly error ΔY is unknown, so the adjusting machine is selected using the estimated assembly error ΔY^*, and an erroneous selection of the adjusting machine occurs.

3 Adjusting machine selection method

In the corrective assembly approach, to maximize the production rate of the relay which satisfies the predetermined assembly tolerance, the optimal adjusting machine which maximizes a selection-probability that ΔY^+ is within the predetermined assembly tolerance must be selected. In this section, we formulate the selection-probability $PE_i(t)$ of adjusting machine M_i in the case where the estimated assembly error $\Delta Y^*=t$, and the reprocessing error $\Delta E_i= y$.

The p.d.f. (probability density function) $f_W(s)$ of the true assembly error $\Delta Y=\Delta W_B-\Delta W_A=s$, and the p.d.f. $f_M(x)$ of the measurement assembly error $\Delta Y^*-\Delta Y=\Delta M_B-\Delta M_A=x$ for the product assembled by a pair of parts A and B are given by Eq. (2).

$$f_W(s)=\int_{-\infty}^{\infty} f_{WA}(\delta)\, f_{WB}(s+\delta)d\delta, \quad f_M(x)=\int_{-\infty}^{\infty} f_{MA}(\delta)\, f_{MB}(x+\delta)d\delta, \tag{2}$$

where $f_{WA}(.)$ and $f_{WB}(.)$ are the p.d.f.s of machining error of parts A and B, and $f_{MA}(.)$ and $f_{MB}(.)$ are the p.d.f.s of measurement error of parts A and B, respectively. When the estimated assembly error $\Delta Y^*=(\Delta W_B-\Delta W_A)+(\Delta M_B-\Delta M_A)=s+x=t$, and the adjusting machine M_i is selected, Eq. (3) must be true for the true reprocessing assembly error $\Delta Y^+=t-x-E_i-y$ to satisfy the predetermined assembly tolerance $|K_\delta|$.

$$-K_\delta \le t-x-E_i-y \le K_\delta \,. \tag{3}$$

In this case, y is any value, so $PE_i(t)$ is given by Eq. (4).

$$PE_i(t)=\int_{-\infty}^{\infty}\int_{t-E_i-y-K_\delta}^{t-E_i-y+K_\delta} f_M(x) f_W(t-x)\, f_{Ei}(y)dxdy, \tag{4}$$

where $f_{Ei}(.)$ is the p.d.f. of reprocessing error. Consequently, the adjusting machine which maximizes the selection-probability $PE_i(t)$ is selected as the optimal machine. The maximum production rate R_g^* yielded in this strategy is given by Eq. (5).

$$R_g^* = \int_{-\infty}^{\infty} \underset{i=1,\ldots,NK}{Max}\left[PE_i(t)\right]dt \,. \tag{5}$$

4 The optimality of the proposed strategy

To present the optimality of the proposed strategy, we compare the maximum production rate R_g^* obtained by Eq. (5) with the production rate R_g obtained by various estimated assembly error ranges $[I^*_i, J^*_i]$ (i=1,2, …,NK) in which a pair of parts A and B selects the adjusting machine M_i. The system parameters are NK=3, $E_1=-2|K_\delta|$, $E_2=0$, $E_3=2|K_\delta|$[μm], $-I^*_1=J^*_3=\infty$, and $-I^*_2(=-J^*_1)=J^*_2(=I^*_3)$, and the other parameters are shown in Table 1. The results for $|K_\delta|$=10,20[μm] and $3\sigma_{Ei}$=0,2.5,5,7.5,10[μm] are shown in Fig.1, where ‘x’ in Fig.1 denotes R_g^*. Table 2 shows R_g^*, the maximum production rate R_{gmax} in R_g, and the estimated assembly error range $[I^*_i, J^*_i]$ which yields R_{gmax}. From Fig. 1 and Table 2, it is presented that R_g^* gives the maximum production rate in all $|K_\delta|$ and $3\sigma_{Ei}$. This means that the optimal adjusting machine is selected using the proposed strategy to maximize the production rate. Furthermore, Table 2 presents that the reprocessing error decreases

R_g^* as $|K_\delta|$ becomes tighter, but has little effect on $[I^*_{\mathrm{i}}, J^*_{\mathrm{i}}]$ which yields R_{gmax} when $|K_\delta|$ is constant.

Table 1: Basic system parameters.

Distribution of $\varDelta W_A$, $\varDelta W_B$	Normal distribution (mean: $\mu_{WA}=\mu_{WB}=0$ [µm], standard deviation: σ_{WA}, σ_{WB}[µm])
Distribution of $\varDelta M_A$, $\varDelta M_B$	Normal distribution (mean: $\mu_{MA}=\mu_{MB}=0$[µm], standard deviation: σ_{MA}, σ_{MB} [µm])
Distribution of $\varDelta E_i$ (i=1,2,3)	Normal distribution (mean: $\mu_{Ei}=0$ [µm], standard deviation: σ_{Ei} [µm])
Machining accuracy of parts A, B	$(3\sigma_{WA}, 3\sigma_{WB})=(30,15)$ [µm]
Measurement accuracy of parts A, B	$(3\sigma_{MA}, 3\sigma_{MB})=(10,10)$ [µm]
Reprocessing accuracy of $\mathrm{M_i}$ (i=1,2,3)	$3\sigma_{Ei}$ [µm]

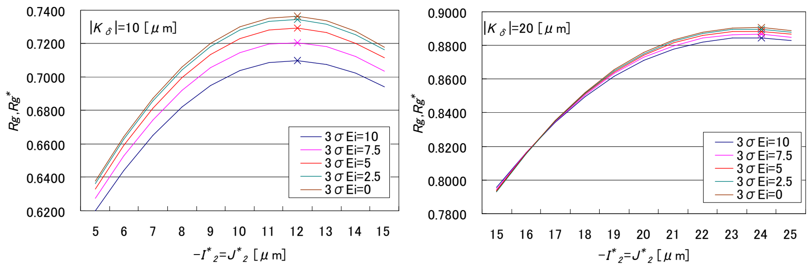

Fig.1: Optimality of the proposed strategy

5 Conclusions

1) The strategy which yields the maximum production rate is proposed, and the optimality of the strategy is presented.

2) The reprocessing error decreases the maximum production rate as the assembly tolerance becomes tighter.

Table 2: R_g^*, R_{gmax}, and $[I^*_{\mathrm{i}}, J^*_{\mathrm{i}}]$

$\lvert K_\delta\rvert$	$3\sigma_{Ei}$	R_g^*	R_{gmax}	$J^*_1=I^*_2$	$J^*_2=I^*_3$
10	0	0.7366	0.7366	-12	12
	2.5	0.7346	0.7346	-12	12
	5	0.7292	0.7292	-12	12
	7.5	0.7208	0.7208	-12	12
	10	0.7100	0.7100	-12	12
20	0	0.8905	0.8905	-24	24
	2.5	0.8896	0.8896	-24	24
	5	0.8884	0.8884	-24	24
	7.5	0.8865	0.8865	-24	24
	10	0.8843	0.8843	-24	24

References:

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