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Reliability Verification Method Concerning the Initiation of Elongated Cumulative Charges in a Metal Shell

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Abstract: The development of the comparative assessment concerning the methods of Elongated Cumulative Charges in a Metal Shell (ECCMS) susceptibility to the initiating pulse will allow to obtain a quantitative estimate of the initiation relative reliability concerning the mass production of ECCMS and newly developed structures. ECCMS susceptibility assessment method to the initiating pulse will allow to obtain the quantitative estimation of the initiation relative reliability concerning mass produced ECCMS and newly developed structures. At that it is necessary that the reliability of a single system functioning has a normal law of dependence at the change of a deteriorating selected parameter. The performed studies found that the proposed method of ECCMS susceptibility estimation to the initiating pulse allows to obtain a quantitative assessment of the relative ECCMS initiation reliability. The use of the proposed methodology allowed to confirm the same reliability of charge initiation fabricated by drawing and by a combined rolling technology with drawing, which accelerated the development of the new technology at least 2 times and made it cheaper more than by 50%. The performed studies allowed to select a spacer steel plate thickness as a deteriorating option between the means of initiation and a charge as a deteriorating parameter. This option allows to obtain a comparative quantitative assessment of the initiation reliability concerning ECCMS charges with minimal cost and sufficient accuracy.

Key words: Explosive cutting, elongated cumulative charges in a metal shell, the production of elongated cumulative charges in a metal shell by drawing and rolling, the reliability of elongated cumulative charge initiation, Russia

INTRODUCTION

Samara State Technical University conducted and carried out the research on the optimization of structures and manufacturing technologies of Elongated Cumulative Charges in a Metal Shell (ECCMS) for many years in order to increase their effectiveness and reliability of their operation at the simultaneous reduction of production and manufacturing costs. The results of development published by Shirokov *et al.* (2015), Kalashnikov *et al.* (1999), Attekov *et al.* (2000) and Poilov *et al.* (2009) showed that there is the potential for equipment design and technology improvement concerning elongated cumulative charges in a metal shell. In this regard, a natural question arises about the estimation methodology concerning the comparative reliability of developed charge initiation as compared to the current production.

Let's consider the comparative assessment procedure concerning the initiation reliability of elongated cumulative charges in a metal shell of varying design as the problem of quantitative initiation probability indicators according to the test results of their initiation from electric detonators, for example, according to GOST9089-75. In order to create a system of methods let's use the method of reliability estimation concerning the operation of single-use systems with a deteriorating parameter change (Gill *et al*., 1981).

MATERIALS AND METHODS

Let's use a spacer plate thickness between an electric detonator according to GOST9089-75 and an elongated cumulative charge in a metal shell which guarantees 100% probability of its initiation, which is confirmed by the appropriate separation of a barrier as a quantitative measure. A test assembly scheme is shown on Fig. 1. The products of 2Tsn type with a current mass production were proposed a test object.

But in all cases the initiation reliability determined by testing results because of the limited number of trials (N) always has a statistical error and some uncertainty (an uncertainty interval). The convergence of probability estimates is improved as N increases and theoretically, at

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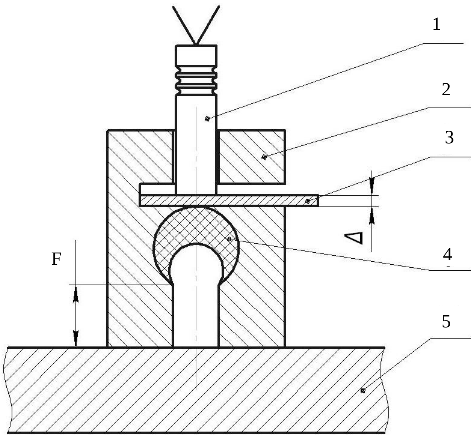

Fig. 1: Test scheme of 2Tsn type product on the initiation reliability according to the system of methods with a deteriorating parameter change; 1: electric detonator in accordance with GOST 7089-75; 2: field assembly; 3: steel plate (deteriorating parameter); 4: DUZ; 5: witness plate, Δ: steel plate thickness

$N \to \infty$ the estimation closes to the actual value of ECCMS initiation reliability by an electric detonator according to GOST9089-75.

Let us assume that the confidence intervals (lower and upper limits) with a given confidence level (γ) are used as the uncertainty intervals. Then, if is the required level of failure initiation probability and $\underline{P}_\gamma$ is the lower confidence limit of a faultless combustion initiation probability, obtained according to N test results with the confident probability γ, then the confirmation condition of the desired reliability level concerning the determination of combustion initiation period is the following one:

$$\underline{P}_\gamma \geq P_\gamma \tag{1}$$

If the condition (Eq. 1) is not satisfied, it is decided not to carry out further tests. At a normal distribution of the measured initiation reliability value there is always the opportunity to observe the dependence of operation-failure frequency (failure-initiation) on the magnitude of a deteriorating parameter (a spacer steel plate thickness) (Tarzhanov, 2003).

In the developed method the calculation of ECCMS initiation reliability critical value is performed according to the experimental curve of failure frequency determination results. This system of methods allows you to determine the value of initiation reliability at a given reliability level and a confidence interval.

It should be noted that the ability to determine the actual ECCMS initiation reliability at a low amount of tests (N<100) may be implemented if its determination reliability is significantly above the desired (P_γ). This leads to the need of higher safety margins than it is actually needed for a given level of reliability provision (Gill *et al*., 1981).

The tests which determine the initiation frequency dependence on the deleteriorating parameter (the thickness of a spacer steel plate) are carried out at initiation frequency change in the range of 0-100%.

In order to develop an initiation frequency curve tests should be carried out using at least 4 levels of initiation energy power density and at least 20 tests shall be performed at every level, which is considered as sufficient for the chosen confidence level. The total amount of tests to determine the critical density of VV initiation power is calculated using the following formula:

$$N_\Sigma = n + k \times 10 \tag{2}$$

Where:

n = The number of experiments required to find the boundaries of 100% of failure and 100% of response
k = The number of levels

The test results are processed according to the method of least squares to calculate the following:

- The values of laser radiation duration at 100% probability of VV charge initiation with the confidence level of 0.95 adopted as a sufficient one at the obtaining of experimental results
- The values of laser radiation duration at 100% probability of VV charge initiation rejection with a confidence level of 0.95 adopted as a sufficient one at the obtaining of experimental results

According to mathematical processing results concerning the experimental dependence of failure frequency on the deteriorating parameter value (steel plate thickness) a critical value is obtained satisfying the following inequality:

$$\Delta > \Delta_{kp} \tag{3}$$

where, Δ_{kp} is the critical value of the deteriorating parameter at 100% probability of a charge initiation. The calculation, the critical value of the deteriorating parameter providing 100% of VV charge initiation is performed by computational-experimental method with the use of information obtained during the tests of an initiation frequency Curve Relative Frequency (IFC) development.

The critical value of the deteriorating parameter calculation, providing 100% of VV charge initiation according to KCHO, is reduced to the obtaining of its standard deviation point estimation $\sigma_{\hat{P}}$ at the set reliability $\hat{P}$ and according to the following Eq. 4:

$$\hat{P} = \frac{\phi[\hat{u}(x_{min})], \text{If } \frac{dP}{dt} \succ 0}{1-\phi[\hat{u}(x_{max})], \text{If } \frac{dP}{dt} \prec 0} \quad (4)$$

Where:

- $\hat{u}(x)$ = The point estimation of the quantile obtained during the processing of test results
- x_{min}, x_{max} = Extreme values limits of laser irradiation critical time provides 100% of initiation and 100% of failure
- $\frac{dP}{dx} \succ 0, \frac{dP}{dx} \prec 0$ = Increasing and decreasing reliability function

The lower confidence limit of VV $\underset{\leftrightarrow}{P}$ initiation reliability is determined by the following Eq. 5:

$$\underset{\leftrightarrow}{P} = \frac{\phi[\hat{u}(x_{min})], \text{If } \frac{dP}{dt} \succ 0}{1-\phi[\hat{u}(x_{max})], \text{If } \frac{dP}{dt} \prec 0} \quad (5)$$

Where:

$$\sigma_{\hat{P}} = \frac{\hat{P} - P}{H_\gamma} \quad (6)$$

Where:

- u_γ^H, $u_\gamma^\sigma(x)$ = A lower and an upper confidence limits of quantiles, respectively
- u_γ = The quantile of the standard normal distribution level γ

The calculation program is designed for the mathematical processing of the results by experimental dependence of the failure frequency $\hat{g}_i(x_i)$; on laser radiation exposure period x_i. The initial data for calculation are given by:

- The table of failure frequency experimental dependence or the experimental dependence of response frequency table (when reliability is an increasing function of a determining parameter)
- The number of determining parameter (k) test levels
- Student criterion (factor) t_y, selected according to the table on the basis of a given confidence level y and the amount of freedom degrees k-2
- Start and end points concerning the dependence graph of failure frequency on the laser radiation exposure time

The calculation of failure probability estimates (operation) and their standard deviations is carried out according to the following Eq. 7:

$$g(x_i) = 1 - P(x_i) = \begin{cases} \frac{m_i}{n_i}, \text{ if } m \neq n, m \neq 0 \\ \frac{1}{n_i+2}, \text{if } m = 0 \\ \frac{n_i+1}{n_i+2}, \text{ if } m = n \end{cases} \quad (7)$$

$$\sigma_{g(\hat{x}_i)} = \begin{cases} \frac{1}{n_j+2}\sqrt{\frac{n_j+1}{n_j+3}}, \text{ if } m_j = 0, m_j \neq n_j \\ \sqrt{\frac{(n_j - m_j)m_j}{n_j^3}}, \text{ if } m_j \neq 0, m_j \neq n_j \end{cases} \quad (8)$$

The calculation of point estimates for normalized quantiles $\hat{u}(x)$ and their standard deviations $\sigma_{\hat{u}(x_j)}$ is performed according to the following Eq. 9 and 10:

$$\hat{u}_j(x_j) = \phi^{-1}\left[\hat{g}(x_j)\right] \quad (9)$$

$$\sigma_{\hat{u}(x_j)} = \sqrt{2\pi}?xp\left(\frac{\hat{u}^2(x_j)}{2}\right)\sigma\hat{g}(x_j) \quad (10)$$

The processing of $\hat{u}(x_j), \sigma_{\hat{u}(x_j)}$ values by the least square method and the determination of the equation $\hat{u}(x) = \hat{a} + \hat{b}x$ (direct regression) is performed according to the following Eq. 11 and 12:

$$\hat{a} = \frac{S_2V_0 - S_1V_1}{S_2S_0 - S_1^2} \quad (11)$$

$$\hat{b} = \frac{S_0V_1 - S_1V_0}{S_2S_0 - S_1^2} \quad (12)$$

where, $\hat{a}$, $\hat{b}$ are the ratios in direct regression Eq. 13:

$$S_0 = \sum_{0=1}^{k} P_j^2 \quad (13)$$

$$S_1 = \sum_{j=1}^{k} P_j^2 x_j;\ S_2 = \sum P_j^2 x_j^2 \tag{14}$$

$$?_j^2 = \frac{1}{\sigma^2_{\hat{u}_\varepsilon(?_i)}} \tag{15}$$

$$V_0 = \sum P_j^2 u(?_j) \tag{16}$$

$$V_1 = \sum P_j^2 u(x_j) x_j \tag{17}$$

The calculation of mathematical expectation point estimates and the standard deviation $\hat{m}_x$ of the determining parameter is carried out according to the following Eq. 18 and 19:

$$\hat{m}_x = \frac{\hat{a}}{\hat{b}} \tag{18}$$

$$\hat{\sigma}_x = -\frac{1}{\hat{b}} \tag{19}$$

The calculation of upper and lower confidence limits concerning a normalized quantile at different values of a defining parameter is performed according to the following Eq. 20 and 21:

$$u^b(x) = \hat{u}(x) + t_j \sigma_{\hat{u}(x)} \tag{20}$$

$$u^H(x) = \hat{u}(x) + t_j \sigma_{\hat{u}(x)} \tag{21}$$

Where:

$$\sigma\hat{u}(x) = \sqrt{\sigma^2_{\hat{a}} + \sigma^2_{\hat{б}} + x^2 + 2k_{\hat{a}\hat{б}} x} \tag{22}$$

$$\sigma^2_{\hat{a}} = \frac{S_2}{S_2 S_0 - S_1^2} \frac{S_{min}}{k-1} \tag{23}$$

$$\sigma^2_{\hat{б}} = \frac{S_0}{S_2 S_0 - S_1^2} \frac{S_{min}}{k-1} \tag{24}$$

$$k_{\hat{a}\hat{б}} = -\frac{S_1}{S_2 S_0 - S_1^2} \frac{S_{min}}{k-1} \tag{25}$$

$$S_{min} = \sum_{j=1}^{k} P_j^2 (\hat{u}_\varepsilon(x_j) - \hat{u}(x_j))^2 \tag{26}$$

The solution of direct reliability task is performed according to the following Eq. 27-29:

$$\hat{P}(x) = \begin{cases} \phi(\hat{u}(x)), \text{if } dP/dx \succ 0 \\ 1-\phi(\hat{u}(x)), \text{ if } dP/dx \prec 0 \end{cases} \tag{27}$$

$$\underset{\sim}{P}(x) = \begin{cases} \phi(\hat{u}(x)), \text{if } dP/dx \succ 0 \\ 1-\phi(\hat{u}(x)), \text{if } dP/dx \prec 0 \end{cases} \tag{28}$$

$$\ddot{P}(x) = \begin{cases} \phi(\hat{u}(x)), \text{if } dP/dx \succ 0 \\ 1-\phi(\hat{u}(x)), \text{if } dP/dx \prec 0 \end{cases} \tag{29}$$

The development of KCHI for the critical time of laser irradiation calculation, providing 100% of VV charge initiation according to the proposed procedure, is performed using the assembly shown on Fig. 1.

ECCMS initiation probability change from electric detonators GOST 9089-75 is provided by the change of the deteriorating parameter (steel plate thickness) value. During the test positives taken The full detonation of ECCMS with the development of "a cumulative knife" and the division of the relevant obstacle is taken as a response criterion.

By varying the thickness of a spacer steel plate they seek of ECCMS initiation probability obtaining within the interval from 0-1 as noted above no less than four values a spacer steel plate thickness.

Further calculations are performed using PC according to above presented formulas to obtain the statistical characteristics of ECCMS initiation probability from a spacer steel plate thickness. We accept a spacer steel plate thickness at the probability of p = 1.0 and the confidence level of $\gamma = 0.95$, considered to be sufficient for experimental research as critical ones.

RESULTS AND DISCUSSION

The test results concerning the proposed method for KCHI dependence development from the deteriorating parameter value and the results of deteriorating parameter critical value calculation of 100% ECCMS initiation of 2Tcn, 13M and 2Tcn types are shown in Table 1 and graphically on Fig. 2.

The processing of performed experiments showed that the critical thickness values of a spacer steel plate at 100% initiation of DUZ make: 1.0 mm for 2Tsn 13M; 1.4 mm for 2Tsn 23.

The calculations are performed using PC. The accuracy of spacer polished steel plates makes ± 0,05 mm by thickness.

The test results for the evaluation of 2Tsn 13M and 2Tsn 23 charge relative reliability initiation by electric detonators ED-8G are presented in Table 1 and in a graphic form on Fig. 2.

Table 1: Comparative test results concerning initiation reliability estimation

	Initiation failure probability (DUZ, % P)					
	Deteriorating parameter value (Steel plate thickness) mm					
Steel plate thickness (mm)	1.4	1.5	1.6	1.8	1.9	2.1
2Tsn 13M	15	25	-	70	80	0
2Tsn 23	0	0	5	20	40	60

DUZ initiation failure probability was calculated out of 20 experiments

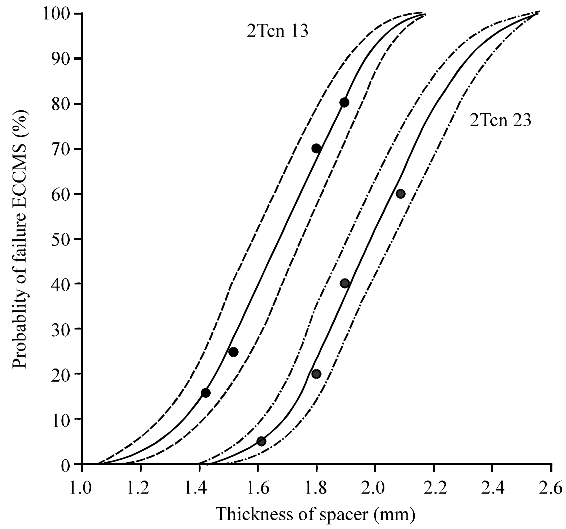

Fig. 2: ECCMS of 2Tsn type initiation failure dependence graph on the value of the deteriorating parameter (a spacer steel plate thickness) using ED-8G

CONCLUSION

The results of performed tests showed the principal evaluation possibility concerning the susceptibility to the initiating impulse of newly developed ECCMS charges and the technologies of their manufacturing as well as the technological control of their initiation reliability.

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