Reliability Assurance of the Welding by Pressure Equipments

Calin Florin Baban, Marius Baban, Ioan Eugen Radu

***Abstract*—Developed initially on the basis of electronic technology, the researches in the field of reliability have proved their generality, so they can be applied to any technical system including the welding by pressure equipments. The structure of the welding by pressure equipments and their specific characteristics result in a more difficult reliability assurance of this type of systems. In this paper, the reliability assurance of the welding by pressure equipment was achieved by reliability modeling and renewal policies. A case study demonstrates the application of the approach.**

***Index Terms*—Goodness-of-fit test, failure detection, integrated system, renewal policy**

I. Introduction

The development of highly sophisticated systems, the rapid progress in technology and the intense global competition enlarged the scope of the notion of quality, to include aspects concerning the time varying performance of the systems. The general property of a system to conserve its performance in time became the specific notion that is reliability.

The structure of the welding by pressure equipments and their specific characteristics result in a more complex reliability analysis of these systems. The poor quantitative information, regarding, especially, the new technical areas integrated in the welding by pressure equipments, has conducted to a relatively high degree of uncertainty in estimating their behavior.

The reliability analysis for these type of systems must be built on the basis of their clear definition, such that the modeling and analyzing of welding by pressure equipments become more completely with the actual techniques. The reliability of the welding by pressure equipments can be defined from a qualitative point of view, as the aptitude of the equipment to realize the specific or basic function, in the given condition, over the specified time interval, aptitude defined quantitative by the accomplish of these functions.

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The mathematical modeling of the welding by pressure equipments reliability is performed on the basic of the time interval elapsed since the initial moment of equipments operation up to the moment of failure. In reliability theory, the concept of failure is defined as the event when at least one of the equipment performances exceeds its tolerance limits.

II. Monitoring the Failure Process of Welding by Pressure Equipments

In order to detect the failure of the equipment, a data acquisition system was developed. The system is based on the deformation during the welding by pressure process. Comparing the deformation value with their reference value, the failure can be detected.

The data acquisition system is composed by: resistive strain gages, strain indicator, connector block, board acquisition, personal computer and is presented in Fig. 1 [1].

The data acquisition is achieved using two N2A-06-S107N-120 strain gages, with a gage factor K_S=2.06. To determine the strains and then the deformation during welding by pressure equipment, the strain gages were connected in half bridge on the opposite sides of the punch electrode of welding by pressure equipment.

The electrical signals generated by strain gages are transmitted to the measurement device. The device is a P-3500 Analog Strain Indicator. The gage factor of the indicator is K_A=1.95 and the analog output is a linear output: 440 $\mu V/\mu\varepsilon$.

The connection between P-3500 and the board acquisition is ensured by a connector block, using the first channel of the board acquisition.

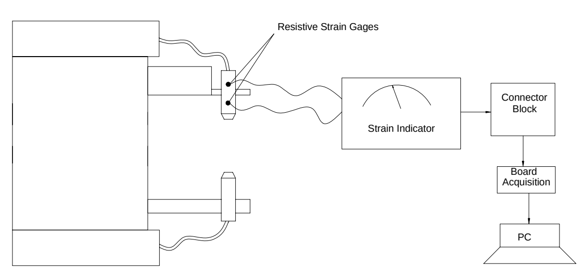

Fig. 1 Data acquisition system

The board acquisition used was a PCI-1200 manufactured by National Instruments. The analog signals which arrived in the board acquisition are transformed in digital signals. This conversion operation is characterized by the sampling rate, which was chosen at 20ks/s. For the PCI-1200 board, the approximation accuracy is 12 bits and the range from input signals is ± 5 V, which means that a digital unity corresponds to a voltage equal to 10/212V=0.0024 V.

The computer for data acquisition was Pentium IV, with extension slot for the board acquisition. The software for reading of the data was developed in C++ language and performed the board acquisition settings and the registration of the experimental data on the PC hard-disk. The signal analysis and processing was performed using Matlab software.

In the case of half-bridge connection we have [4]:

$$\frac{U_e}{U_i} = \varepsilon \frac{K_s}{2} \quad (1)$$

or:

$$\varepsilon = \frac{2}{K_s} \cdot \frac{U_e}{U_i} \quad (2)$$

where U_i, U_e are the input and output voltage of half-bridge connection and is the deformation.

The indication of the P-3500 device is:

$$\varepsilon^* = \frac{4}{K_A} \cdot \frac{U_e}{U_i} \quad (3)$$

Because the analog output of P-3500 is 440 μV/με and for the PCI 1200 a digital unity corresponds to 0.0024 V, the relation (3) can be written:

$$\frac{U_e}{U_i} = \frac{K_A}{4} \cdot \frac{0.0024}{440} \cdot U_d \quad (4)$$

where U_d is the board acquisition output voltage.

Taking into account (4) and (2), we obtain:

$$\varepsilon = \frac{1}{2} \cdot \frac{0.0024}{440} \cdot \frac{K_A}{K_S} \cdot U_d \quad (5)$$

III. Assurance of the Welding by Pressure Equipments

A. Reliability Modeling of the Welding by Pressure Equipments

In the reliability modeling, the reliability measures are defined using the statistical model for the time-to-failure of the equipment. The statistical model for reliability is the cumulative distribution function. Denoted by F(t), the cumulative distribution function represents the probability that the equipment fails after a specified time of functions.

The essential step in reliability description is the adoption of the distribution law which will model the reliability. The adoption of the distribution laws can be performed by a goodness-of-fit test based on the theory of hypothesis testing. According to this theory, the null hypothesis H_0 regarding the distribution law and the alternate hypothesis H_1 which excluded the distribution law selected by the H_0 hypothesis are formulated. A decision between the two hypotheses is taken according to a goodness-of-fit test and is affected by the first (α) and second (β) risks.

One of the most used goodness-of-fit test is Kolmogorov-Smirnov test, which uses the times-to-failure of the equipment under the observation. For this test, the distribution law is accepted if and only if [3]:

$$\sup_{1 \le i \le n} \left| F(t) - \hat{F}(t) \right| < e_{1-\alpha}(n) \quad (6)$$

where F(t) and $\hat{F}(t)$ are the true and estimated cumulative distribution function and $e_{1-\alpha}(n)$ is the (1-α) percentile of the Kolmogorov-Smirnov distribution. The parameters of the proposed distribution are unknown and must be estimated from the experimental data. The most common method is the least squares estimation, which will be used in this paper.

Combining physical analysis and experimental data, two distribution laws were proposed for the reliability modeling of welding by pressure equipments: power law [7] and Weibull law [8].

B. Renewal Policies

The renewal policies are used to increase equipments reliability by preventive renewals of the system prior to failure. The preventive renewal eliminates the cumulative wear and thus prolongs the time to failure of the system.

A renewal policy is specified by the scheduled times of preventive renewals and may be deterministic or random events, according to the type renewal policy. In the event of systems failure, renewals are carried out at random times, whereas preventive renewals may be periodic or non-periodic events, according to the type of renewal policy [3], [5]. The periodic renewal policy is deterministic, as it is characterized by a constant time interval between two successive preventive renewals. The non-periodic renewal policies are based on system age or wear and they are random renewal policies.

In this paper, two renewal policies will be considered: the block replacement policy and the age replacement policy [3]. The block replacement policy (BRP) is the simplest preventive policy. According to this policy, the system is restored to its initial state either upon failure or at equally time intervals kT (k=1,2,…). The disadvantage of BRP policy is the inflexible planning, so that the preventive policy may be performed shortly after a renewal upon failure has been carried out.

The age replacement policy (ARP) is a random renewal policy. In this random renewal policy, preventive renewal is performed if and only if the system has reached a specific age x.

Several criteria may be used in formulating renewal policies [3]. In this paper, the minimization of the average maintenance cost rate criterion will be used for the welding by pressure equipments. In order to evaluate the maintenance cost, the cost of a failure is considered as unity and the cost of preventive renewals is expressed by fraction *a* of the unity.

In the case of BRP policy, the average maintenance cost rate between two successive preventive renewals includes the cost a of a preventive renewal and the cost of the renewals upon failure which appear in [kT,(k+1)T]. Because the mean number of failure in this time interval is the renewal function H(T), the average maintenance cost rate is:

$$c_{BRP} = \frac{a + H(T)}{T} \quad (7)$$

The impediment in calculating the C_{BRP} cost lies in the difficulty or impossibility of calculation the Laplace transforms for the two life distributions proposed to model the reliability of the equipments.

For the ARP policy, the maintenance cost of the system is considered equal to unity if the system fails before it reaches age x and equal to a in the opposite case. Dividing the average maintenance cost by the mean lifetime, we get:

$$c_{ARP} = \frac{F(x) + aR(x)}{\int_0^x R(t)\,dt} \qquad (8)$$

Minimizing expression (9), the equation of the age when preventive renewal should be performed is obtained:

$$z(x^*)\int_0^x R(t)\,dt + R(x^*) = \frac{1}{1-a} \qquad (9)$$

The average maintenance cost of renewal policy must be compared to the average maintenance cost when no preventive renewals are carried out. We describe this situation as the failure replacement policy (FRP). In this case, the average maintenance cost is:

$$c_{FRP} = \frac{1}{m} \qquad (10)$$

IV. INTEGRATED SYSTEM FOR RELIABILITY ASSURANCE OF THE WELDING BY PRESSURE EQUIPMENTS

The integrated system for reliability modeling was developed using Matlab software and is presented in Fig. 2.

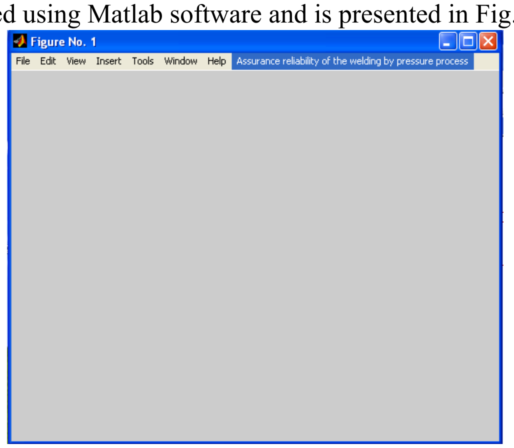

Fig. 2. System interface for reliability modeling

The menu Assurance reliability of the welding by pressure equipment consists of:

a) Data Acquisition: to open the file in which the times-of-failure registered by the data acquisition system are saved.

b) Reliability Modeling: to perform the Kolmogorov-Smirnov goodness-of-fit test for power and Weibull laws. (Fig. 3).

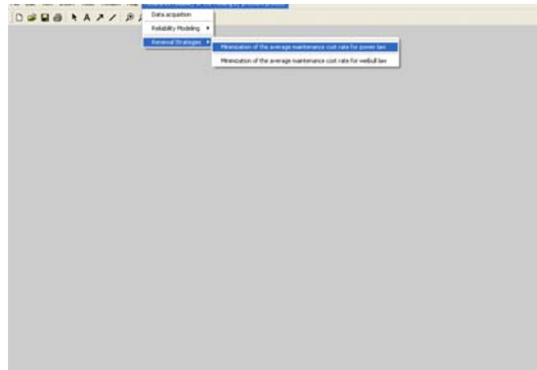

Fig. 3. Kolmogorov-Smirnov goodness-of-fit test submenu

c) Renewal Policies: to design the renewal policies using the average maintenance cost rate minimization criterion (Fig. 4).

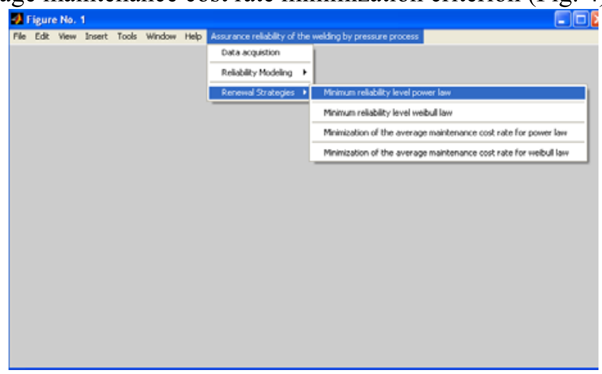

Fig. 4. Renewal Policies submenu

V. CASE STUDY

The system for reliability modeling was applied for an equipment of welding by pressure used in the automotive industry. We assumed that after each failure, the cumulative wear of the tool is eliminated (it is of the “good as new” type).

The time to failure was achieved using the data acquisition system. During the welding by pressure equipment, the deformation can be computed using relation (5). Comparing the deformation value with the deformation value when the tool is good (Fig. 5) and when it fails (Fig. 6), the time-to-failure can be registered.

Using the data acquisition system, the following times to failure of the tool were obtained (in cycles): 2455, 1769, 2129, 2633, 2417, 1430, 2045, 2298, 2389, 2233, 1944, 2355 and were saved in the Timp_data.txt file, which was used as input data for the Kolmogorov-Smirnov goodness-of-fit test.

Using the *Test Kolmogorov-Smirnov* command from *Reliability Modeling* submenu, the general reliability model was adopted. The risk of the first order was adopted at α=0.15. Because only for the power law the relation (6) is true, this law was adopted. The parameters of the power law were also computed: $\hat{\delta} = 4.434;\ \hat{b} = 2584.167$.

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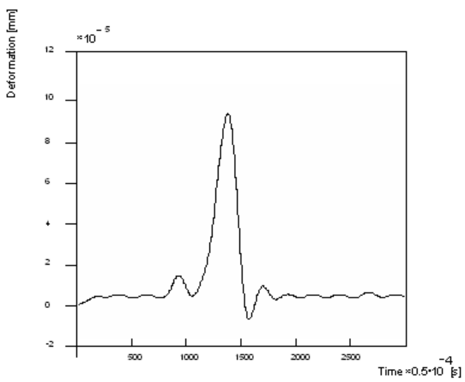

Fig. 5 Deformation graphic for a new electrode

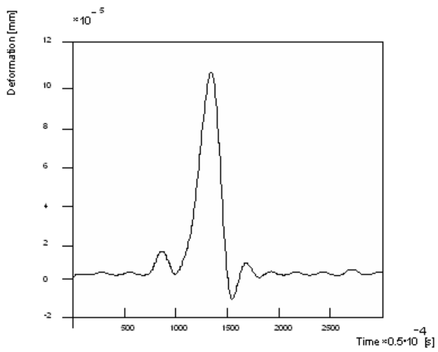

Fig. 6 Deformation graphic for a failure electrode

Suppose that the cost of preventive is 35% of the cost of a renewal upon failure (a=0.35), the age x^* after which the preventive renewal should be performed was computed using option *Minimization of the average maintenance cost rate* for power law from *Renewal Strategies* submenu: x^*=1624 cycle. The average maintenance cost rate for ARP and FRP were also computed: $C_{ARP}= 3.9553 \cdot 10^{-4}$ cycles^{-1}, $C_{BRP}= 4.7425 \cdot 10^{-5}$ cycles^{-1}, so that $C_{ARP} < C_{BRP}$. Thus, the average maintenance cost of the ARP policy is less than in the case of FRP policy, and the reliability function becomes R(1624)=0.87.

VI. Conclusions

For the reliability modeling of the welding by pressure equipments, a data acquisition system for the identification of their failure was developed. Using the experimental information obtained by the data acquisition system, the reliability analysis was performed by the Kolmogorov-Smirnov goodness-of-fit test. After the reliability modeling, the renewal policies were designed. An integrated software system was developed using Mathlab for the reliability assurance of the welding by pressure equipment. A case study for an equipment of welding by pressure used in the automotive industry is presented to demonstrate the application of the integrated software system.

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