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DETERMINATION OF THE ACTUAL STATE STRAIN CHARACTER OF ACCUMULATOR PRESSURE VESSELS

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ABSTRACT
Critical stress states highly depend not only on types and the distribution of stresses but also the intensity and the character of changes. A large number of pressure vessels, during its whole life, are exposed to a variable pressure that is oscillating around a constant value. A special case of pressure vessels are accumulator vessels exposed to the pre-stressing state due to the permanently internal pressure in the situation out of the work, which is conditioned by their application. The loading character in real systems is often stochastic. The application of stochastic changes can not be directly used for the determination of basic fatigue characteristics. For these reasons, stochastic curve is replaced with the lawful one, which should have the same effect on the fatigue and durability of the part of the mechanical system. Lawful curve is obtained using corresponding interpretation of stochastic functions recorded on real mechanical system by strain gauges.
Keywords: pressure vessels, stress-strain analysis, strain gauges.

1. INTRODUCTION
Pressure vessels are designed for continuous operation of the forging process with press machines and are exposed to internal pressure changes whose nature is unknown. In this sense, the measurement with strain gages of the stress-strain state of the outer mantle are made to determine not only the character of the changes but also the frequency of changes to which vessels have been exposed during the forging process. Stresses to which pressure vessels may have been exposed could have only unidirectional character of the change, which could be measured and defined during the operation of the pressing machine.

2. EXPERIMENTAL RESEARCH
Three measurement points on the vessels are installed. The points S1 and S4 are positioned approximately at the middle of the vessel height, where the theoretically highest stresses and strains could be expected. Measuring point S2 is on the support ring zone, and measuring point S3 is on the part of the vessel on dished end and that zone is regarded as potentially dangerous place. Data acquisition was performed with a frequency of 10 [Hz] using 8-channel measuring system "Spider 8-30" and the accompanying software "Catman" and biaxial strain gauges of type 1-XY91-10/120 ("HBM" Darmstadt, Germany). The vessels are compressed air batteries in the initial state of pre-stressing, the constant pressure in the vessels is about 270 [bar]. According to the fact that the initial

state is not 0 [bar], stresses are calculated so as to show stresses in the absolute respect, i.e. from 0 [bar] up to the actual working stresses and as such are shown in Diagram 1.
The process of monitoring and recording of changes in deformation conditions on the outer mantle of vessels was carried out over the five characteristic treatments that were usually performed, as follows: 25 t ingot forging, 15 t ingot forging, making the ring, cutting, circular shaping.

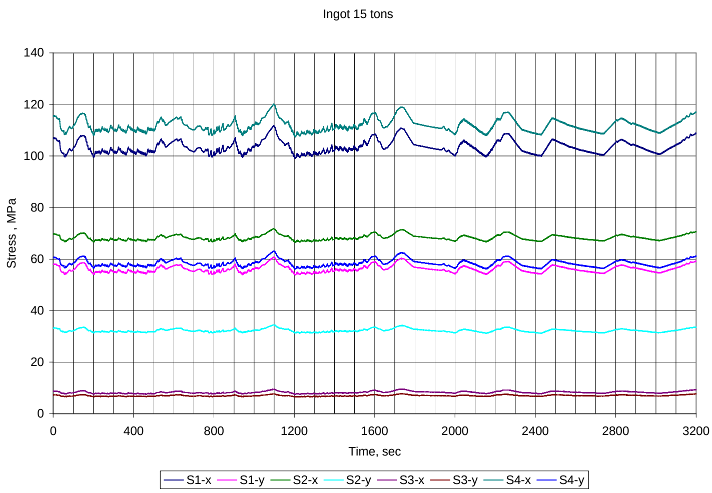

Diagram 1. Stress changes during the forging process of 15 t ingot

As shown in Diagram 1, it is clear that the character of the stress change on the outer vessel mantle is stochastic (random). Stress changes are evident at all points in two orthogonal directions, with the fact that the highest intensities are in the middle of the vessel (S1 and S4) and are lower to dished end (S2 and S3), respectively. The values of measured stress in [MPa], for all four measurement points, are given in Table 1.

3. STATISTICAL ANALYSIS OF RESULTS

In order to further analysis there is a need for the results to be statistically processed due to its quantity. The results of statistical analysis, for all five recorded operations of 15t ingot forging, are presented in Table 1.

Table 1. Statistical values for stress changes during 15t ingot forging operations

INGOT 15 tons								
Measuring point	S1-x	S1-y	S2-x	S2-y	S3-x	S3-y	S4-x	S4-y
No. of samples	31994	31994	31994	31994	31994	31994	31994	31994
MEAN	103,512	56,175	68,335	32,291	8,297	7,005	111,85	58,399
STAND. DEVIATION	2,463	1,366	1,038	0,645	0,414	0,242	2,447	1,368
CUMULATIVE	1	1	1	1	1	1	1	1
MIN	99,07	53,89	66,54	31,22	7,51	6,48	107,4	56,10
MAX	111,80	60,78	71,784	34,50	9,55	7,73	120,1	63,15
MODE	101,76	55,239	67,926	32,030	7,970	6,816	110,35	57,62
MEDIAN	103,00	55,908	68,135	32,158	8,216	6,966	111,34	58,11
MIN / MAX	0,8861	0,8866	0,9270	0,9050	0,785	0,839	0,893	0,888

The choice of a representative distribution is done with processing of statistical data such as comparing the mean value MEAN, MEDIAN and MODE. As it can be seen from Table 1, for each operation individually, these three values are equal and with sufficient accuracy it can be assumed that this is a normal distribution (Gaussian distribution).

The selected test points are representative and for these places a combined or summary function are made that should be with a sufficient degree of confidence with all recorded forging operations. Examples of selected normal distribution for the characteristic measuring point S1-x and the highest stress in the circular direction, are shown in Diagram 2.

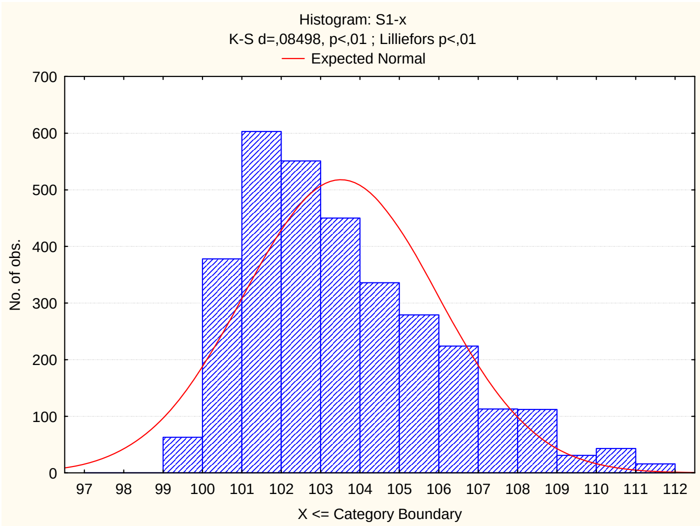

Diagram 2. Observed stress distribution and expected normal distribution of stress S1-x

In the presented Diagram 2, it is clearly evident that the highest incidence is for the lower stress levels corresponding to the so-called "easy stress range". Mild asymmetry indicates that the distribution could be accurately described with a ''log-normal'' or ''Weibull's distribution'', but due to the large number of recorded data, which exceed the recommended values for testing of normality, here it is taken to be a normal positive asymmetric distribution, because the asymmetry is less than 1 or MODE <MEAN. Table 2 shows the characteristic values and mathematical patterns describing the function of the incidence of stress S1-x in the overall production program of the press machine.

Table 2. Characteristics and forms of density function distribution of stress S1-x

No.	Forging operation	Mean stress μ	Standard deviation σ*	Frequency [%]	The theoretical form of the function of normal distribution $f(S_{4-x})$
1.	Ingot 15t	103,51	2,46	75	$f(S)=\frac{1}{2{,}46\sqrt{2\pi}}\cdot e^{-\frac{1}{2}\left(\frac{S-103{,}51}{2{,}46}\right)^2}$
2.	Ingot 25t	97,28	4,92	23	$f(S)=\frac{1}{4{,}92\sqrt{2\pi}}\cdot e^{-\frac{1}{2}\left(\frac{S-97{,}28}{4{,}92}\right)^2}$
3.	Ring	106,34	2,46	2	$f(S)=\frac{1}{2{,}46\sqrt{2\pi}}\cdot e^{-\frac{1}{2}\left(\frac{S-106{,}34}{2{,}46}\right)^2}$
4.	Cutting	108,64	5,24	---	$f(S)=\frac{1}{5{,}24\sqrt{2\pi}}\cdot e^{-\frac{1}{2}\left(\frac{S-108{,}64}{5{,}24}\right)^2}$
5.	Shaping	101,49	2,94	---	$f(S)=\frac{1}{2{,}94\sqrt{2\pi}}\cdot e^{-\frac{1}{2}\left(\frac{S-101{,}49}{2{,}94}\right)^2}$
6.	Summary function	102,13	3,02	100	$f(S)=\frac{1}{3{,}02\sqrt{2\pi}}\cdot e^{-\frac{1}{2}\left(\frac{S-102{,}13}{3{,}02}\right)^2}$

The range of stress distribution for the standard normal distribution of the incidence cumulative function with the area of data included 4σ*, which means that practically 99.99% of data is covered, is shown in the Diagram 3.

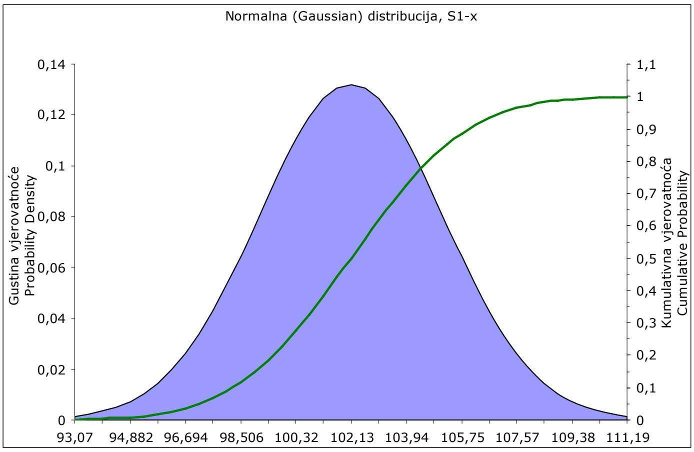

Diagram 3. The distribution density and the cumulative probability of stress S1-x occurrence for a summary function

Taking into account that the combined (summary) function of occurrence frequency has a normal distribution and as such replaces the partial functions, it can be taken in further studies, with sufficient accuracy, the largest number of expected stresses are between the minimum and maximum stress. Summary results of representative cycle asymmetry coefficient of stress on the middle and dished end of vessel in two orthogonal direction to the outer mantle vessels are shown in Table 4.

Table 4. Coefficients of asymmetry (R) of stress changing cycles on the outer mantle of the vessel

Measuring point/Direction	S1-x	S1-y	S3-x	S3-y
$R = \sigma_{min} / \sigma_{max}$	0,84	0,81	0,68	0,74

4. CONCLUSIONS

The character of the stress change is with unidirectional variability with a coefficient of asymmetry R ≈ 0.8 in the middle, and R ≈ 0.7 in the zone of the dished end. This character of the change clearly indicate that all changes taking the place at a relatively high medium stress with very small amplitude of stress changes. As a working medium pressure level, for the summary distribution function, the pressure of 285 [bar] is marked, while the minimum and maximum values are 260 and 310 [bar], which corresponds to the minimum and maximum stress values of 93 and 111 [MPa], as shown in Diagram 3. These working pressures determine the size of the stresses which will be used for fatigue tests that determine the curve of the working dynamic strength, and input data for further fatigue tests with constant amplitude and for the accurate determination of the residual life of the pressure vessel. Determination of stress-strain type changes based on estimates, and not on actual changes could have a significant effect on the determination of fatigue and residual life of the pressure vessel.

5. REFERENCES

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