

STRAIN GAUGES MEASUREMENTS FOR STRAINS AROUND SOME CYLINDRICAL LIFTING BUTTONS

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ABSTRACT

In the paper are presenyed some experimental results for strain gauges measurements completed around some lifting buttons welded on a horizontal cylinder

Keywords: lifting buttons

GENERAL ASPECTS

The experimental device used in order to complete the experimental strain gauges measurements is presented in figure 1 below:

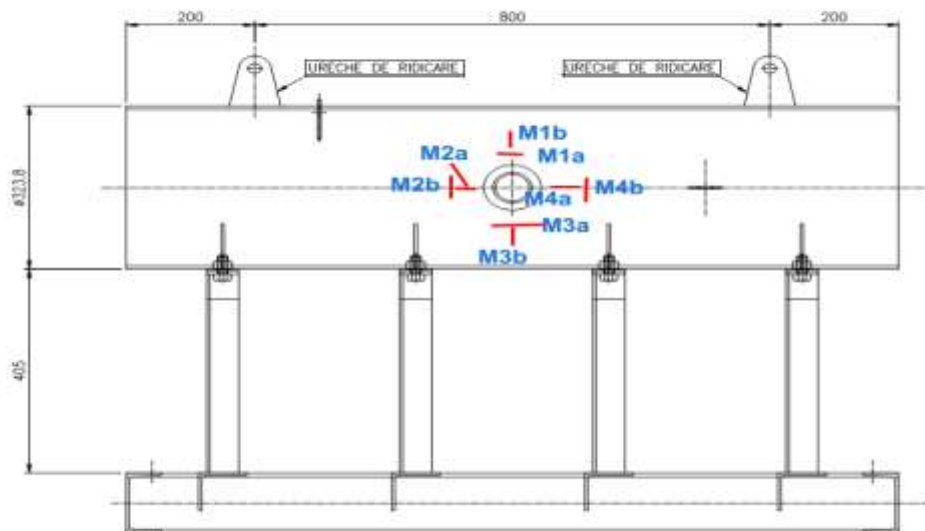


Figure 1. The experimental device

There are two lifting buttons: one is welded directly on the cylinder and the other one is welded on an intermediary reinforcing pad.

In figure 1 are presented the locations of the strain gauges used for the experimental measurements:

- M1a,b and M3a,b are located near the shell-button junction, M1a and M3a being located on the longitudinal direction and M1b and M3b on the circumferential direction;
- M2a and M4a are located on the longitudinal direction and M2b and M4b, on the circumferential direction;
- the same position have the strain gauges M1a,b – M4a,b located near the reinforcing pad;

The total number of strain gauges was sixteen, eight of them being located near the shell-button junction and the other eight near the reinforcing pad, in the same positions

The experimental measurements have been completed using the device presented in figure 1. The main horizontal cylinder has the external diameter 324.8 mm and the thickness 6.35 mm and the lifting buttons are pipes with 60.3 mm external diameter and 3.91 mm thickness. The reinforcing pad has a 5 mm thickness

The lifting force has been realized with a laboratory crane and the entire process was around 700 s long (see figure 2 below):

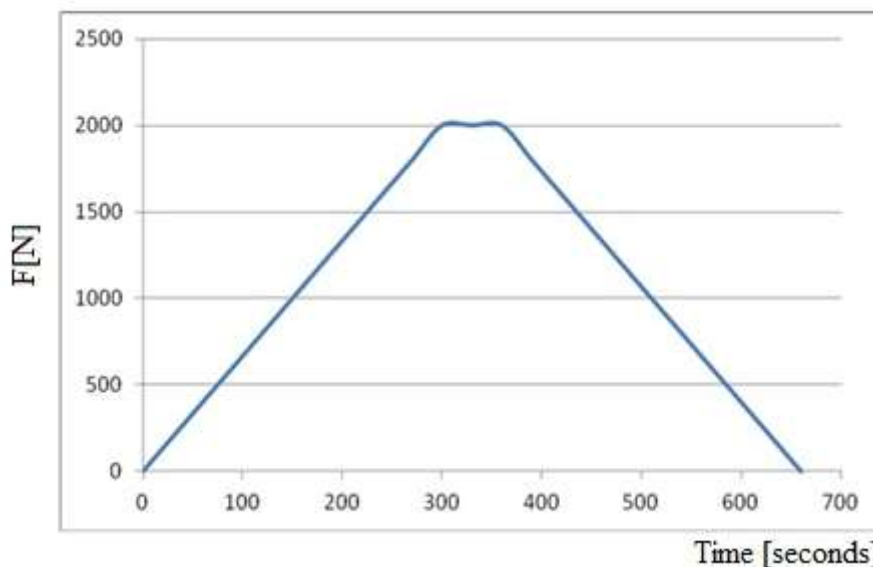


Figure 2. Time dependence force during the loading and unloading process

From the above time dependence curve it can be noticed that the entire lifting process lasted about 11 minutes. The experimental measurements have been completed in a continuous mode, but for safety reasons some reference values have been stored for every 200 N variation of the lifting force. The experimental measurements have been completed during the increasing and decreasing values of the lifting force.

EXPERIMENTAL RESULTS

The strain values received from strain gauges are presented in tables 1 and 2: in table 1 are presented the values received from the strain gauges welded directly on the cylinder and in table 2 the values received from the strain gauges located near the reinforcing pad.

Table 1. Strain values - buttons welded directly on the horizontal cylinder

Time	Force	M1a-M1b		M2a-M2b		M3a-M3b		M4a-M4b	
		ϵ_{1a}	ϵ_{1b}	ϵ_{2a}	ϵ_{2b}	ϵ_{3a}	ϵ_{3b}	ϵ_{4a}	ϵ_{4b}
s	N	$\mu\text{m/m}$	$\mu\text{m/m}$	$\mu\text{m/m}$	$\mu\text{m/m}$	$\mu\text{m/m}$	$\mu\text{m/m}$	$\mu\text{m/m}$	$\mu\text{m/m}$
0,00	0,00	0	0	0	0.15	0	0	0	0
30,00	200,00	15,20	0,304	1,520	2,950	14,972	0,299	1,500	1,464
60,00	400,00	30,24	0,604	3,024	2,948	29,7864	0,595	2,984	2,913
90,00	600,00	42,66	0,853	4,266	4,159	42,0201	0,840	4,210	4,109
120,00	800,00	52,9	1,058	5,290	5,157	52,1065	1,042	5,221	5,095
150,00	1000,0	65,02	1,300	6,502	6,339	64,0447	1,280	6,417	6,263
180,00	1200,0	76,46	1,529	7,646	7,454	75,3131	1,506	7,546	7,365
210,00	1400,0	90,9	1,818	9,090	8,862	89,5365	1,790	8,971	8,756
240,00	1600,0	106,46	2,129	10,646	10,379	104,863	2,097	10,507	10,255
270,00	1800,0	115,74	2,314	11,574	11,284	114,003	2,280	11,423	11,149
300,00	2000,0	122,58	2,451	12,258	11,951	120,741	2,414	12,098	11,808
330,00	2000,0	122,44	2,448	12,244	11,937	120,603	2,412	12,084	11,794
360,00	2000,0	122,34	2,446	12,234	11,928	120,504	2,410	12,074	11,785
390,00	1800,0	114,58	2,291	11,458	11,171	112,863	2,257	11,309	11,037
420,00	1600,0	105,39	2,107	10,539	10,276	103,814	2,076	10,402	10,152
450,00	1400,0	89,99	1,799	8,999	8,774	88,641	1,772	8,882	8,668
480,00	1200,0	75,69	1,513	7,569	7,380	74,559	1,491	7,471	7,2918
510,00	1000,0	64,36	1,287	6,436	6,276	63,404	1,268	6,353	6,200
540,00	800,00	52,37	1,047	5,237	5,106	51,585	1,031	5,169	5,044
570,00	600,00	42,23	0,844	4,223	4,117	41,599	0,832	4,168	4,068
600,00	400,00	29,93	0,598	2,993	2,918	29,488	0,589	2,954	2,883
630,00	200,00	15,04	0,300	1,504	1,467	14,822	0,296	1,485	1,449
660,00	0,00	0	0	0	0	0	0	0	0

With the values presented in the tables 1 and 2 have been represented the following time dependence curves: figures 3...6 for the buttons welded directly on the cylinder and 7...10 for the buttons welded on the reinforcing pad.

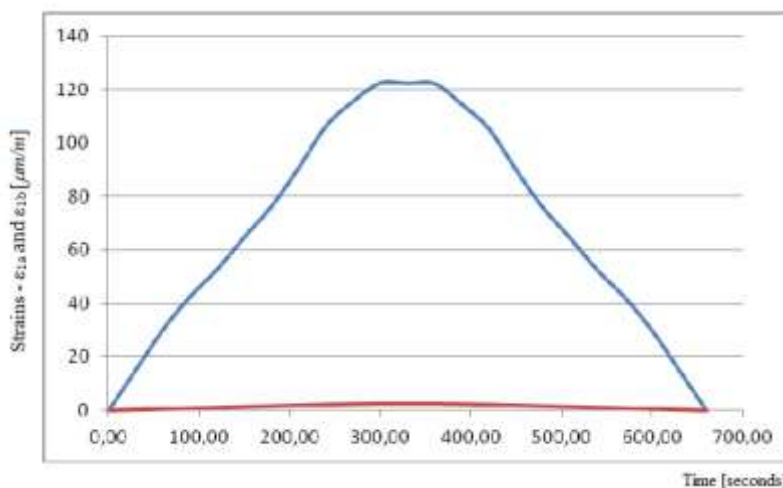


Figure 3. Strains against time – strain gauges M1a, M1b Buttons welded directly on the horizontal cylinder

Table 2. Strain values - buttons welded on the reinforcing pad

Time	Force	M1a-M1b		M2a-M2b		M3a-M3b		M4a-M4b	
		ϵ_{1a}	ϵ_{1b}	ϵ_{2a}	ϵ_{2b}	ϵ_{3a}	ϵ_{3b}	ϵ_{4a}	ϵ_{4b}
s	N	$\mu\text{m/m}$	$\mu\text{m/m}$	$\mu\text{m/m}$	$\mu\text{m/m}$	$\mu\text{m/m}$	$\mu\text{m/m}$	$\mu\text{m/m}$	$\mu\text{m/m}$
0,00	0,00	0	0	0	0	0	0	0	0
30,00	200,00	10,840	0,440	2,168	0,027	9,647	0,66	2,139	0,026
60,00	400,00	16,440	0,640	3,288	0,041	14,631	0,96	3,245	0,040
90,00	600,00	29,840	1,200	5,968	0,074	26,557	1,8	5,890	0,073
120,00	800,00	38,440	1,520	7,688	0,096	34,211	2,28	7,588	0,094
150,00	1000,0	46,540	1,880	9,308	0,116	41,420	2,82	9,186	0,114
180,00	1200,0	57,500	2,380	11,5	0,143	51,175	3,57	11,350	0,142
210,00	1400,0	64,480	2,620	12,896	0,1612	57,387	3,93	12,728	0,159
240,00	1600,0	74,360	3,040	14,872	0,1859	66,180	4,56	14,678	0,183
270,00	1800,0	79,720	3,260	15,944	0,199	70,950	4,89	15,736	0,196
300,00	2000,0	85,460	3,520	17,092	0,213	76,059	5,28	16,869	0,211
330,00	2000,0	85,320	3,500	17,064	0,213	75,934	5,25	16,842	0,210
360,00	2000,0	85,400	3,520	17,080	0,213	76,006	5,28	16,857	0,210
390,00	1800,0	78,922	1,578	15,784	0,197	70,241	2,367	15,579	0,194
420,00	1600,0	73,616	1,472	14,723	0,184	65,518	2,208	14,531	0,181
450,00	1400,0	63,835	1,276	12,767	0,159	56,813	1,915	12,601	0,157
480,00	1200,0	56,925	1,138	11,385	0,142	50,663	1,707	11,237	0,140
510,00	1000,0	46,074	0,921	9,214	0,115	41,006	1,382	9,095	0,113
540,00	800,00	38,055	0,761	7,611	0,095	33,869	1,141	7,512	0,093
570,00	600,00	29,541	0,590	5,908	0,073	26,292	0,886	5,831	0,072
600,00	400,00	16,275	0,325	3,255	0,040	14,485	0,488	3,212	0,040
630,00	200,00	10,731	0,214	2,146	0,026	9,551	0,321	2,118	0,0265
660,00	0,00	0	0	0	0	0	0	0	0

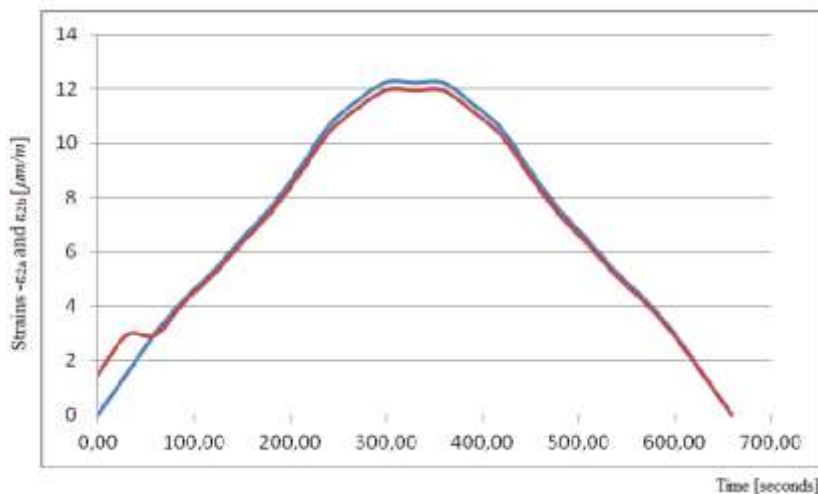


Figure 4. Strains against time – strain gauges M2a, M2b Buttons welded directly on the horizontal cylinder

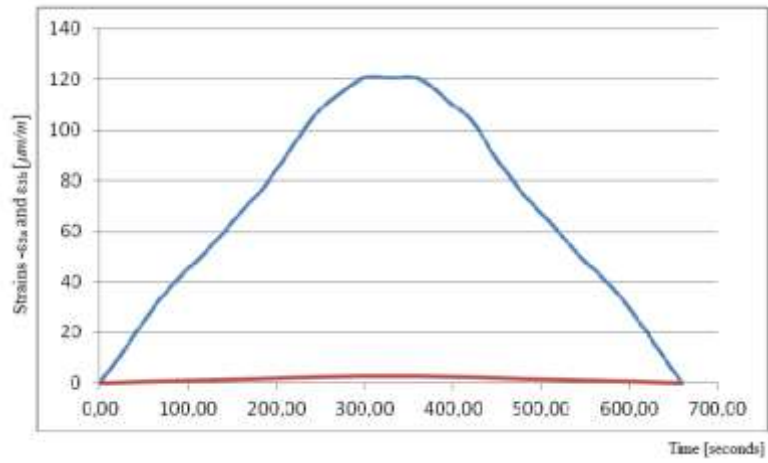


Figure 5. Strains against time – strain gauges M3a, M3b Buttons welded directly on the horizontal cylinder

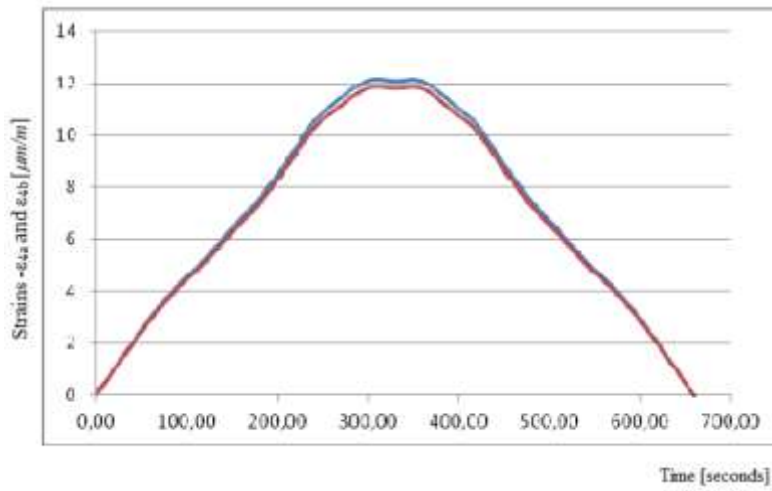


Figure 6. Strains against time – strain gauges M4a, M4b Buttons welded directly on the horizontal cylinder

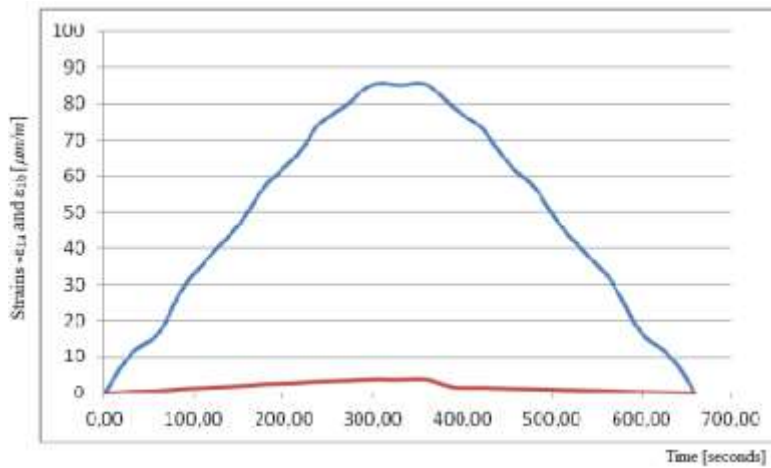


Figure 7. Strains against time – strain gauges M1a, M1b Buttons welded on a reinforcing pad

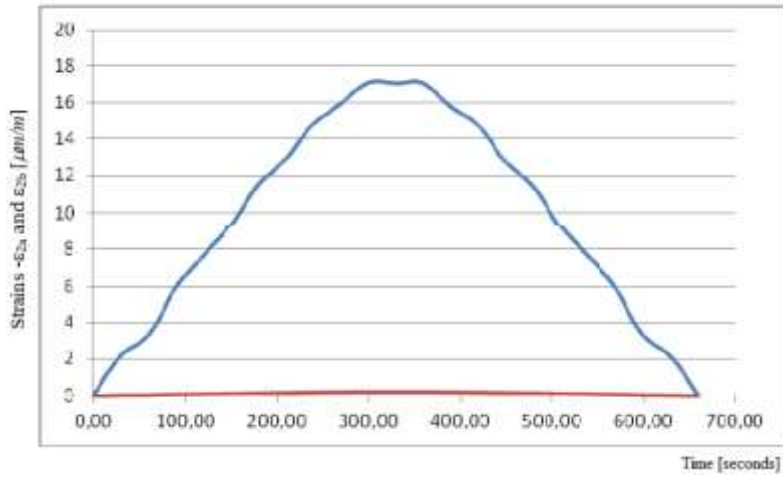


Figure 8. Strains against time – strain gauges M2a, M2b Buttons welded on a reinforcing pad

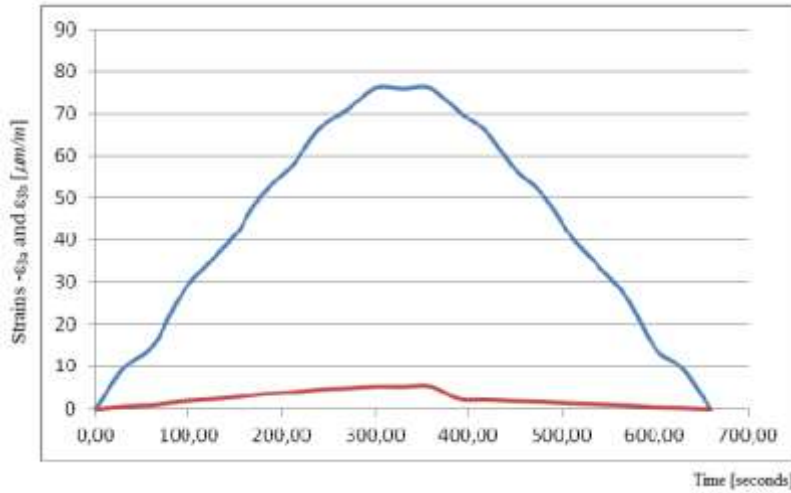


Figure 9. Strains against time – strain gauges M3a, M3b Buttons welded on a reinforcing pad

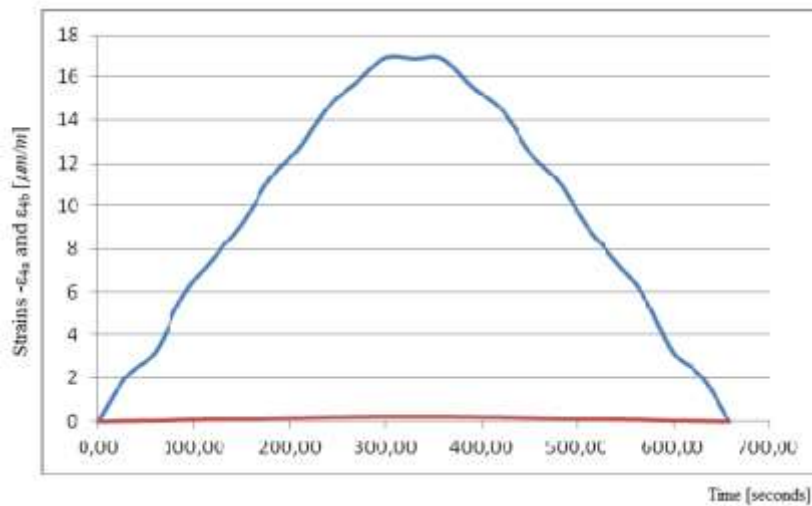


Figure 10. Strains against time – strain gauges M4a, M4b Buttons welded on a reinforcing pad

Analyzing the above strain time dependence it can be drawn the following conclusions:

- the maximum strains, for the buttons welded directly on the cylinder appear in the strain gauges M1a and M3a (located on longitudinal direction) and have about the value of $122 \mu\text{m}/\text{m}$;
- the maximum strains, for the buttons welded on the reinforcing pad appear on the same strain gauges M1a and M3a (located on longitudinal direction) and have approximately the value of $85 \mu\text{m}/\text{m}$;
- the presence of the reinforcing pad produces a decreasing of strains with about 35%;
- during the unloading process it have been obtained approximately the same values of strains with those measured during the loading process; this is a real proof that the entire measurement experiment has been developed in the elastic range and at the end of unloading process no remaining deformations appeared.

Table 3. Stresses – buttons welded directly on the cylinder

Time	Force	M1a-M1b		M2a-M2b		M3a-M3b		M4a-M4b	
		σ_{1a}	σ_{1b}	σ_{2a}	σ_{2b}	σ_{3a}	σ_{3b}	σ_{4a}	σ_{4b}
<i>s</i>	<i>N</i>	<i>MΠα</i>	<i>MΠα</i>	<i>MΠα</i>	<i>MΠα</i>	<i>MΠα</i>	<i>MΠα</i>	<i>MΠα</i>	<i>MΠα</i>
0,00	0,00	0	0	0	0	0	0	0	0
30,00	200,00	3,360	1,069	0,431	0,425	3,310	1,052	0,4262	0,420
60,00	400,00	6,686	2,126	0,859	0,847	6,585	2,094	0,848	0,837
90,00	600,00	9,432	3,000	1,211	1,195	9,290	2,955	1,196	1,180
120,00	800,00	11,696	3,720	1,502	1,482	11,520	3,664	1,483	1,464
150,00	1000,0	14,375	4,572	1,846	1,821	14,160	4,504	1,823	1,799
180,00	1200,0	16,905	5,377	2,171	2,142	16,651	5,296	2,144	2,116
210,00	1400,0	20,097	6,392	2,582	2,547	19,796	6,297	2,549	2,516
240,00	1600,0	23,538	7,487	3,024	2,983	23,185	7,374	2,985	2,946
270,00	1800,0	25,589	8,139	3,287	3,243	25,206	8,017	3,245	3,203
300,00	2000,0	27,102	8,621	3,482	3,434	26,695	8,491	3,437	3,392
330,00	2000,0	27,071	8,611	3,478	3,431	26,665	8,481	3,433	3,389
360,00	2000,0	27,049	8,604	3,475	3,428	26,643	8,475	3,430	3,386
390,00	1800,0	25,334	8,058	3,254	3,210	24,954	7,937	3,213	3,171
420,00	1600,0	23,302	7,412	2,993	2,953	22,953	7,301	2,955	2,917
450,00	1400,0	19,896	6,329	2,556	2,521	19,598	6,234	2,523	2,490
480,00	1200,0	16,736	5,323	2,150	2,121	16,485	5,243	2,122	2,095
510,00	1000,0	14,232	4,527	1,828	1,803	14,018	4,459	1,805	1,781
540,00	800,00	11,579	3,683	1,487	1,467	11,405	3,627	1,468	1,449
570,00	600,00	9,337	2,970	1,199	1,183	9,197	2,925	1,184	1,168
600,00	400,00	6,619	2,105	0,850	0,838	6,519	2,073	0,839	0,828
630,00	200,00	3,327	1,058	0,427	0,421	3,277	1,042	0,422	0,416
660,00	0,00	0	0	0	0	0	0	0	0

Using the strains presented in tables 1 and 2 the following stresses have been calculated:

- the longitudinal and circumferential stresses around the lifting buttons welded directly on the cylinder – table 3;
- the longitudinal and circumferential stresses around the lifting buttons welded on the reinforcing pad – table 4;

Table 4. Stresses – buttons welded on the reinforcing pad

Time	Force	M1a-M1b		M2a-M2b		M3a-M3b		M4a-M4b	
		σ_{1a}	σ_{1b}	σ_{2a}	σ_{2b}	σ_{3a}	σ_{3b}	σ_{4a}	σ_{4b}
s	N	MПа	MПа	MПа	MПа	MПа	MПа	MПа	MПа
0,00	0,00	0	0	0	0	0	0	0	0
30,00	200,00	2,411	0,811	0,478	0,148	2,163	0,781	0,472	0,146
60,00	400,00	3,655	1,224	0,725	0,225	3,279	1,175	0,715	0,222
90,00	600,00	6,637	2,231	1,316	0,409	5,955	2,146	1,299	0,404
120,00	800,00	8,548	2,868	1,696	0,528	7,669	2,756	1,673	0,521
150,00	1000,0	10,352	3,481	2,053	0,639	9,289	3,350	2,026	0,631
180,00	1200,0	12,794	4,314	2,536	0,789	11,482	4,158	2,503	0,779
210,00	1400,0	14,344	4,827	2,844	0,885	12,871	4,647	2,807	0,874
240,00	1600,0	16,543	5,570	3,280	1,021	14,845	5,365	3,238	1,008
270,00	1800,0	17,735	5,972	3,517	1,095	15,916	5,752	3,471	1,080
300,00	2000,0	19,014	6,408	3,770	1,173	17,064	6,175	3,721	1,158
330,00	2000,0	18,982	6,394	3,764	1,171	17,035	6,160	3,715	1,156
360,00	2000,0	19,001	6,404	3,767	1,173	17,052	6,171	3,718	1,157
390,00	1800,0	17,449	5,550	3,482	1,084	15,593	5,151	3,436	1,070
420,00	1600,0	16,276	5,177	3,248	1,011	14,545	4,805	3,205	0,998
450,00	1400,0	14,113	4,489	2,816	0,876	12,612	4,166	2,779	0,865
480,00	1200,0	12,586	4,003	2,511	0,781	11,247	3,715	2,478	0,771
510,00	1000,0	10,187	3,240	2,032	0,632	9,103	3,007	2,006	0,624
540,00	800,00	8,414	2,676	1,679	0,522	7,519	2,484	1,657	0,515
570,00	600,00	6,531	2,077	1,303	0,405	5,836	1,928	1,286	0,400
600,00	400,00	3,598	1,144	0,718	0,223	3,215	1,062	0,708	0,220
630,00	200,00	2,372	0,754	0,473	0,147	2,120	0,700	0,467	0,145
660,00	0,00	0	0	0	0	0	0	0	0

The values presented in tables 3 and 4 have been transposed in time dependence functions:

- the longitudinal and circumferential stresses around the buttons welded directly on the cylinder (figures 11...14);
- the longitudinal and circumferential stresses around the buttons welded on the reinforcing pad (figures 15...18);

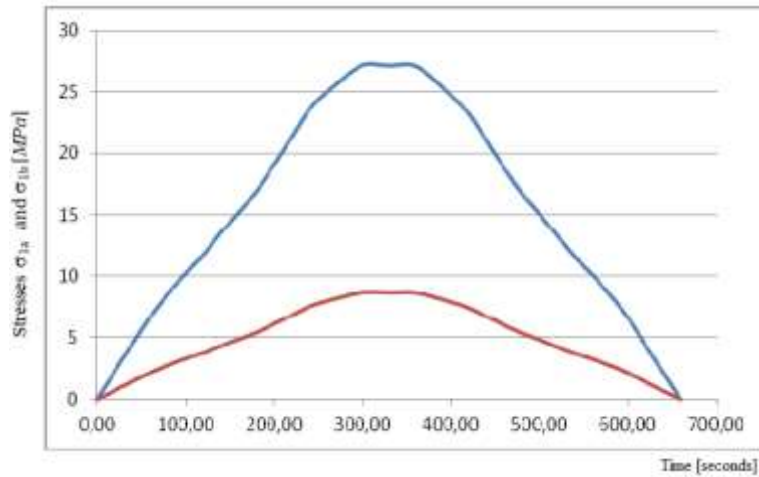


Figure 11. Stresses against time - M1a, M1b
Buttons welded directly on the cylinder

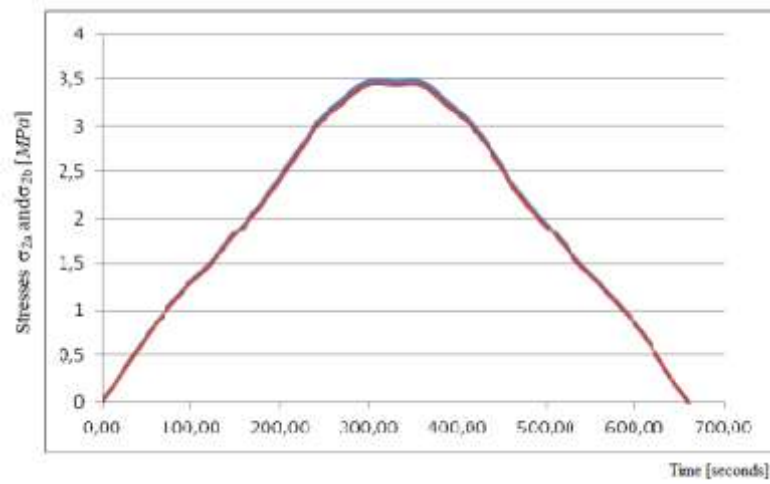


Figure 12. Stresses against time – M2a, M2b
Buttons welded directly on the cylinder

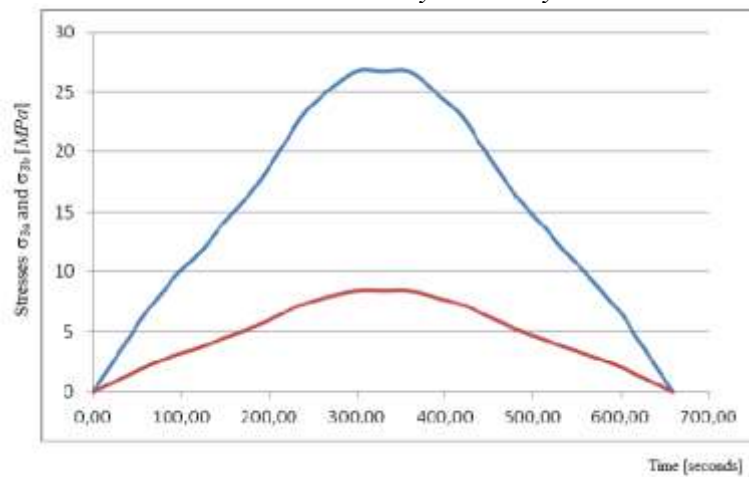


Figure 13. Stresses against time – M3a, M3b
Buttons welded directly on the cylinder

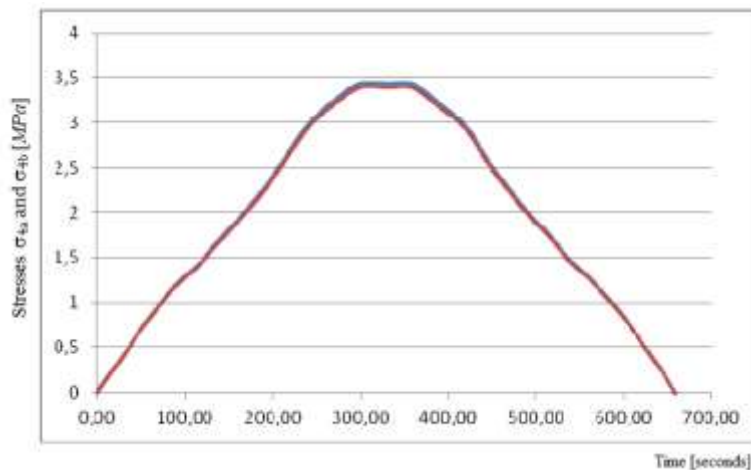


Figure 14. Stresses against time – M4a, M4b Buttons welded directly on the cylinder

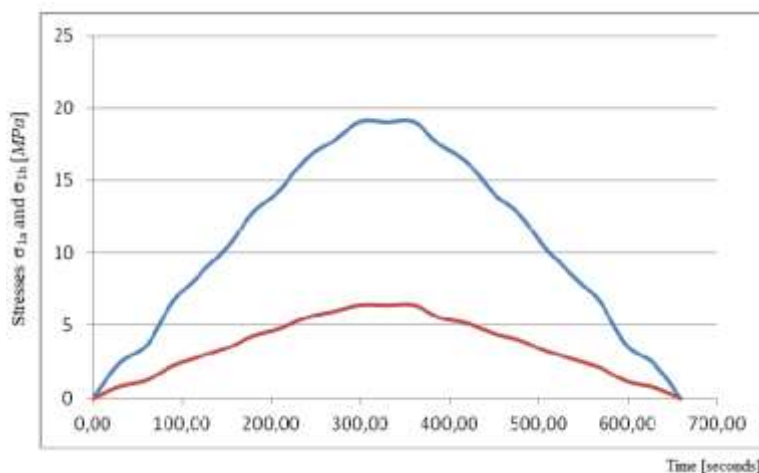


Figure 15. Stresses against time - M1a, M1b Buttons welded on the reinforcing pad

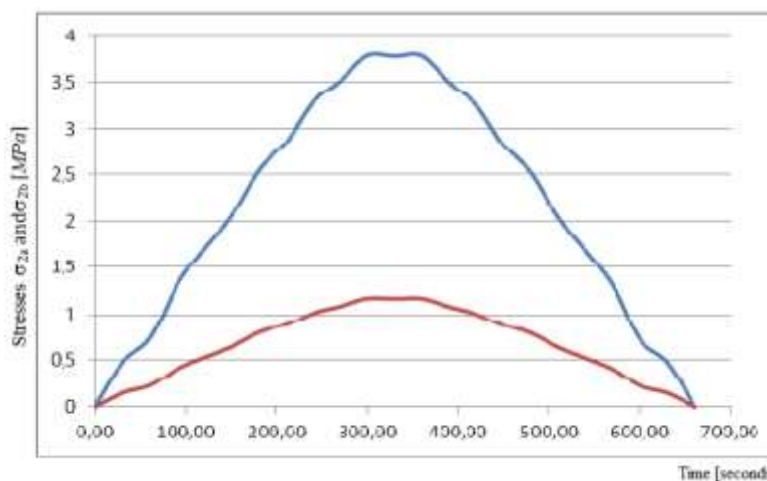


Figure 16. Stresses against time – M2a, M2b Buttons welded on the reinforcing pad

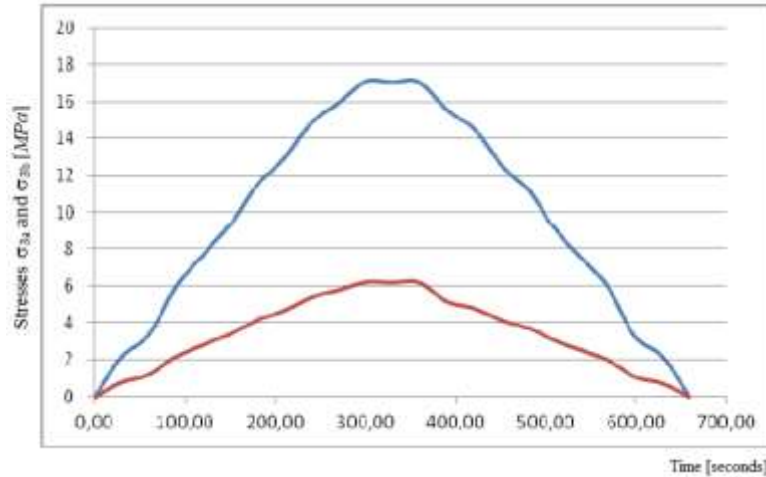


Figure 17. Stresses against time – M3a, M3b
Buttons welded on the reinforcing pad

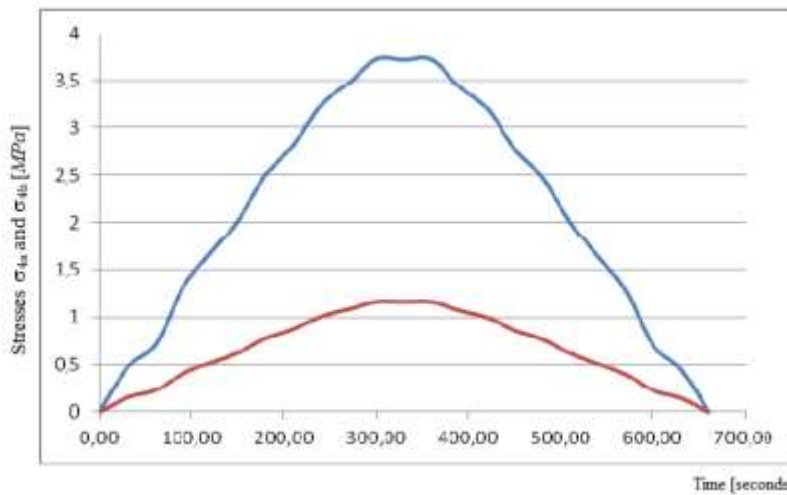


Figure 18. Stresses against time – M4a, M4b
Buttons welded on the reinforcing pad

Analysing the stresses time dependence functions (figures 11-18) the following conclusions can be enlighten:

- the maximum normal stresses appear around the lifting buttons welded directly on the horizontal cylinder and have about the values of 27 MPa (figures 11, 13); the values of stresses are similar in the points M1 and M3 due to symmetry considerations;
- the normal stresses from the points M2 and M4, for the buttons welded directly on the horizontal cylinder are also similar but have smaller values, around 3 MPa;
- the maximum stresses that appear around the lifting buttons welded on a reinforcing pad are approximately 19 MPa (figures 15, 17) and have similar values due to symmetry considerations; the presence of the reinforcing pad produces a decreasing of the highest level of the stresses with about 33%;

- the maximum stresses from the points M2 and M4 for the buttons welded on a reinforcing pad have similar values and are around 3 MPa;

A synthesis of the above experimental results (for the maximum values of the stresses) is presented in the table 5 below, together with a comparison between the FEA and the experimental results.

Table5 - FEA and experimental results

Results	Maximum stresses – buttons welded on the horizontal cylinder	Maximum stresses – buttons welded on the reinforcing pad
Experimental results [MPa]	27.07	19.01
Theoretical results [MPa]	27,74	19,75
Relative error [%]	2.5%	3.8%

The maximum errors resulted from the strain gauges experiments proves that the entire experiment has a very good accuracy, the maximum difference between the theoretical (FEA) and experimental results being less than 4 %.

CONCLUSIONS

In the paper are presented experimental results obtained from strain gauges measurements completed around some lifting buttons in two separate cases: when the lifting buttons are welded directly on the horizontal cylinder and when the lifting buttons are welded on an intermediate reinforcing pad.

The results obtained are accurate, the maximum relative error being less than 4%.

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