ОБЪЕДИНЕННЫЙ
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RECENT ADVANCES IN PRECISION LASER CUTTING FOR THE ATLAS HADRON CALORIMETER ABSORBERS PRODUCTION

Presented at the International ATLAS Collaboration Conference, November 1995, CERN, Geneva, Switzerland

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1995

The Cutting Tools.

The precision laser cutting facility (LCF) consists of several high-tech blocks:

- CO -laser, 0.5-5 kW power, single mode, continuous wave operation, with the stable output radiation parameters;
- the precision two-direction moveable table with the process area up to 2 by 4 meters;
- the computer system for cutting scheme designing and operation control;
- cooling, vacuum and gas supply systems.

The LCF is used for cutting of almost any type of sheet material to any complicated profile. Sheet thickness might be as much as some centimeters, and the cutting speed reaches a few meters per minute.

However, to meet the severe tolerance requirements on the ATLAS hadron calorimeter "spacer" parameters (the cut edge needs no final machining, the final dimensions are within close tolerances) both the staff of the LCF and JINR experts have completed a large scale R&D works. These are:

- the technique for indirect "spacer" dimensions measuring with an accuracy of 20 μm was developed;
- the LCF operation process parameters (laser power, cutting speed etc.) to avoid flashes on the edge were adjusted;
- the arrangement of "spacers" on a steel sheet billet and their cutting priorities were optimized for each LCF;
- the number of experimental cuttings were produced to determine the process of deviations of "spacer" dimensions and the corrections of cutting program were done as a result .

Starting July 1994 we had began our searches to find the best master & spacer plates manufacturing. We had a set of meetings and negotiations with 18 located in Russia Federation and FSU organisations which have tehnological laser fasility. Most of these 18 organisation refused to accept our order mainly because of very tight tolerance demands.

Now, there are two plants the JINR had signed contracts with to produce experimental sets of "spacers" with required quality. They are:

- "UNIVERSALMASH" Plant (Kirov's Plant), S.-Petersburg;
- Research Center of Technological Lasers of Russian Academy of Science (RCTL RAS), Shatura.

There is the TRUMPF LCF in the "UNIVERSALMASH" Plant, that has 1 kW power laser and 1.8 m by 2 m process area table with an passport accuracy of 30 μm. There is the billet feed system in the laser cutting shop area.

The LCF in operation at the RCTL RAS, has TL-1.5 laser (1.5 kW power) and 1.2 m by 1.7 m process area table with a certificated accuracy of 100 μm. One can see the external view of LCF in the Fig. 1. Another LCF of the same kind is planned to be installed. There is a lift-and-transport system in the shop area.

The cutting speed for a steel sheet of 4 mm thick is about 0.5 meter per minute for both of the plants. The time needed for one period of "spacers" cutting is approximately half an hour. We estimate that the daily output of one LCF (including all time expenditures, one-shift a day operation) is the complete set of "spacers" for one submodule (16 periods 12 "spacers" each).

Besides, the JSC "Laser Complexes" in Shatura and PTI Belarus Academy of Sciences (Pepublic of Belarus) in Minsk carry the laser cutting process to perfection. There is a plan to install the LCF in JINR, Dubna also.

Measurement Technique.

The required tolerances of "spacer" dimensions are very tight: ±100 μm for overall dimensions, ±50 μm for hole locations, - 50 μm for holes diameter.

So, the measuring technique has to have an accuracy not worse than 20 μm. The digital calliper "Mitutoyo" was chosen as a measuring device, obtained at JINR due to kind M.Nessi help. We determined its real accuracy by measuring the master gauges. It appeared to be 10 μm. However, most of the parameters, except H, can not be measured directly. To obtain other "spacer" parameters the cylinder gauges and calibration prisms have to be used. This technique one can see in Fig.2. The true dimensions are calculated next. The accuracy of this technique is about 20 μm as it was estimated by us.

It is important to carry out the measurements at the specified temperature, as the temperature change of $10^{\circ}C$ causes up to 12 μm deviation at 100 mm length.

Measurements of "spacer" dimensions by hand is a very time consuming process. Therefore, the system for an automatic measurement of "spacers" is being devised in JINR. It will contain the precision two-directions moveable table and the system for tracking the "spacer" edge based on CCD-camera or stable laser beam.

The Method of Correction.

The measured "spacer" parameter can be represented as:

$$X_{meas} = X_{prog} + dX_{apar} + \mathrm{sqrt}\,(dX^2_{stat} + dX^2_{meas}),$$

where X_{prog} is the parameter in the computer program of cutting; dX_{apar} is the systematic deviation of parameter due to cutting process (the finite cutting width, the dependence of cutting width from cutting direction due to elliptic polarization of laser radiation, heating of the steel sheet billet etc.); dX_{stat} is the statistic deviations, or - the facility accuracy; and, finally, dX_{meas} is the measurement error.

To obtain the systematic deviation of "spacer" parameter, two or three periods of "spacers" have to be produced. After measuring, the distribution of deviations of real dimensions from tabulated ones is plotted (Fig. 3,4). The distribution maximum position determines dX_{apar} and its width: $dX_{stat} + dX_{meas}$. It is better to estimate the LCF accuracy from the distribution of differences of deviations for the same "spacers" (Fig. 5). The correction of X_{prog} for the cutting program is made using the given systematic deviation.

This correction technique had been tested and implemented at RCTL RAS Shatura. The table of "spacers" dimensions cut with the corrected program is presented in Fig. 6. Only 6 of 116 measured parameters are out of tolerances.

At the present time the program correction is completed at "UNIVERSALMASH" S.-Petersburg also. The recent results obtained are shown in Fig.7,8,9. It is important to note that the measurements at S.-Petersburg were carried out at +12°*C* temperature, so the A,B-parameters distribution (Fig.8) has -38 µm deviation from '0' (A,B-parameters are of large dimensions). With the temperature elongation factor taken into account, the distribution will be moved up to about +30 µm.

So, no A,B-parameters correction is needed. Others parameters comply with the requirements and they should not be changed also. What is the most important the positions of the holes are maintained strictly.

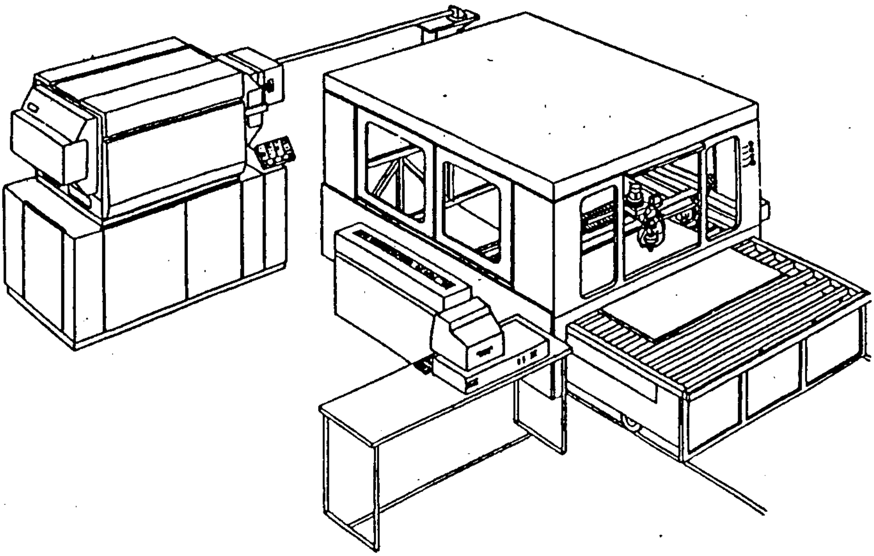

Figure 1. The external view of the precision laser cutting facility at the Research Center of Technological Lasers of Russian Academy of Science, Shatura, Russia.

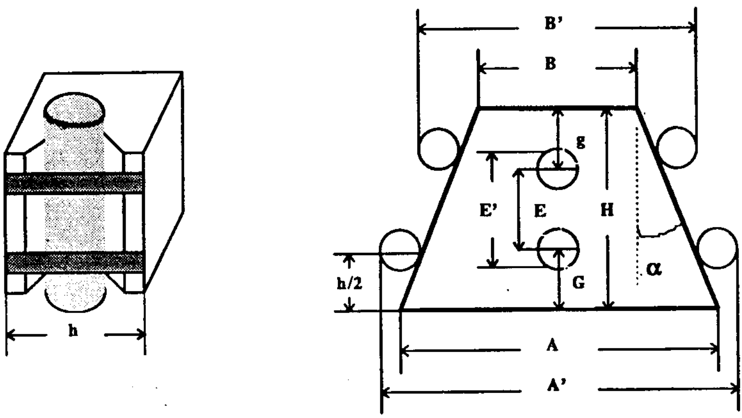

Figure 2. The "spacer" drawing. The parameters A, B cannot be measured directly as angles are bevelled. The parameters A', B', E', G' are measured by using the cylinder gauges and calibration prisms shown left.

N	A	B	H	E	g	G	ΔA	ΔB	ΔH	ΔE	Δg	ΔG
7	230,34	220,44	101,09	70,00	15,66	15,50	- 0,26	- 0,26	+0,09	0,00	+0,16	0,00
7'	230,36	220,47	101,08	69,97	15,66	15,49	- 0,24	- 0,23	+0,08	- 0,03	+0,16	- 0,01
7"	230,30	220,44	101,03	69,96	15,58	15,48	- 0,30	- 0,26	+0,03	- 0,04	+0,18	- 0,02
1	240,20	230,22	101.97	69,99	16,03	16,01	- 0,20	- 0,18	- 0,03	- 0,01	+0,03	+0,01
1'	240,12	230,12	101,97	69,97	16,05	15,99	- 0,28	- 0,28	- 0,03	- 0,03	+0,05	- 0,01
1"	240,17	230,18	102,11	69,96	16,19	15,95	- 0,22	- 0,22	+0,11	- 0,04	+0,19	- 0,05
8	248,55	238,56	102.09	70,00	16,08	15,97	- 0,35	- 0,24	+0,09	0,00	+0,08	- 0,03
8'	248,70	238,63	101.93	69,97	16,00	15,99	- 0,20	- 0,17	- 0,07	- 0,03	0,00	- 0,01
8"	248,64	238,61	102,04	69,98	16,06	15,97	- 0,26	- 0,19	+0,04	- 0,02	+0,06	- 0,03
2	261,33	248,53	132,03	99,90	16,11	15,95	- 0,27	- 0,17	+0,03	- 0,10	+0,11	- 0,05
2'	261,31	248,44	132,12	99,92	16,26	15,92	- 0,29	- 0,26	+0,12	- 0,08	+0,26	- 0,08
2"	261,37	248,54	131,95	99,93	16,04	15,88	- 0,23	- 0,16	- 0,05	- 0,07	+0,04	- 0,12
9	274,16	261,20	131,97	99,98	16,05	15,94	- 0,24	- 0,20	- 0,03	- 0,02	+0,05	- 0,06
9'	274,16	261,17	131,92	99,96	16,02	15,93	- 0,24	- 0,23	- 0,08	- 0,04	+0,02	- 0,07
9"	274,06	261,12	132,06	100,04	15,96	15,94	- 0,34	- 0,28	+0,06	+0,04	- 0,04	- 0,06
3	286,96	274,00	131,98	99,98	16,01	15,94	- 0,24	- 0,20	- 0,02	- 0,02	+0,01	- 0,06
3'	286,99	274,00	131,90	100,02	15,95	15,87	- 0,21	- 0,20	- 0,10	+0,02	- 0,05	- 0,13
3"	286,88	273,96	132,08	99,98	16,06	16,00	- 0,32	- 0,24	+0,08	- 0,02	+0,06	0,00
10	301,71	286,82	151,96	119,96	16,07	15,95	- 0,19	- 0,18	- 0,04	- 0,04	+0,07	- 0,05
10'	301,71	286,85	152,04	119,95	16,10	16,04	-0,19	- 0,15	+0,04	- 0,05	+0,10	+0,04
10"	301,74	286,82	152,03	119,94	16,09	15,98	- 0,16	- 0,18	+0,03	- 0,06	+0,09	- 0,02
4	316,44	301,48	151,86	119,89	16,05	15,94	- 0,26	- 0,22	- 0,14	- 0,11	+0,05	- 0,06
4'	316,49	301,45	152,04	119,91	16,07	15,98	- 0,21	- 0,25	+0,04	- 0,09	+0,07	- 0,02
4"	316,49	301,52	151,91	119,88	16,07	16,01	- 0,21	- 0,18	- 0,09	- 0,12	+0,07	+0,01
11	331,15	316,25	152,08	119,99	16,03	15,98	- 0,25	- 0,25	+0,08	- 0,01	+0,03	- 0,02
11'	331,15	316,26	151,94	120,03	16,07	15,89	- 0,25	- 0,24	- 0,06	+0,03	+0,07	- 0,11
11"	331,12	316,25	151,96	119,99	16,01	15,86	- 0,28	- 0,25	- 0,04	- 0,01	+0,01	- 0,14
5	349,74	331,00	191,93	159,91	16,10	15.94	- 0,26	- 0,20	- 0,07	- 0,09	+0,10	- 0,06
5'	349,73	331,04	191,94	159,88	16,13	15,98	- 0,27	- 0,16	- 0,06	- 0,12	+0,13	- 0,02
5"	349,73	330,99	191,95	159,92	16,10	15,98	- 0,27	- 0,21	- 0,05	- 0,08	+0,10	- 0,02
12	372,06	349,57	240,58	160,00	15,56	64,97	- 0,54	- 0,29	+0,08	0,00	+0,06	- 0,03
12'	372,14	349,54	240,54	159,92	15,59	65,07	- 0,46	- 0,32	+0,04	- 0,08	+0,09	+0,07
12"	372,12	349,56	240,53	159,91	15,66	65,06	- 0,48	- 0,30	+0,03	- 0,09	+0,16	+0,06
6	372,14	368,16	50,58	341,89	----	----	- 0,46	- 0,34	+0,08	- 0,11	----	----
6'	372,11	368,18	50,58	341,88	----	----	- 0,49	- 0,32	+0,08	- 0,12	----	----
6"	372,11	368,15	50,57	341,88			- 0,49	- 0,35	+0,07	- 0,12		

Figure 3. The table of "spacers" dimensions produced at RCTL RAS Shatura.

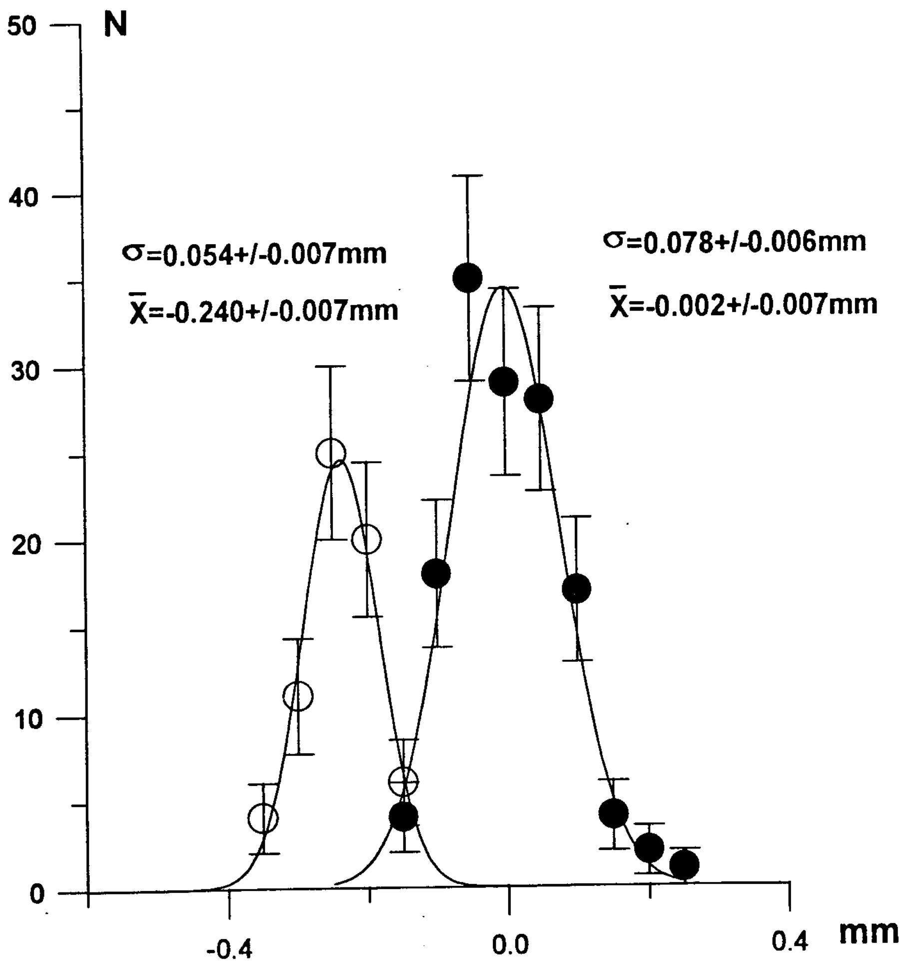

Figure 4. The distribution of deviations of real dimensions (Fig. 3) from tabulated ones.
A,B parameters ○ H,E,G,g parameters ●

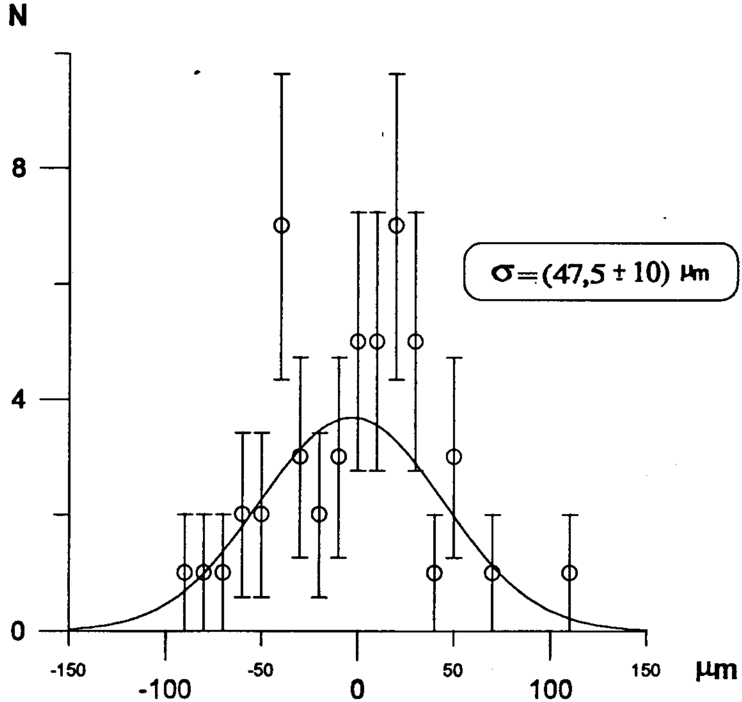

Figure 5. The ΔP - values distribution

$\Delta P = dP_{I\ period} - dP_{II\ period}$; dP=(dA, dB, dH, dE, dG)

N	A	B	H	E	G	ΔA	ΔB	ΔH	ΔE	ΔG
1	240,34	230,40	102,02	69,99	15,98	- 60	0	+20	- 10	- 20
1'	240,37	230,49	101,97	69,99	15,99	- 30	+90	- 30	- 10	- 10
2	261,53	248,72	131,90	99,92	15,97	- 70	+20	- 100	- 80	- 30
2'	261,57	248,76	131,89	99,90	15,97	- 30	+60	- 110	- 100	- 30
3	287,10	274,26	131,90	99,97	15,98	- 100	+60	- 100	- 30	- 20
3'	287,18	274,20	131,95	99,97	15,99	- 20	0	- 50	- 30	- 10
4	216,62	301,71	151,96	119,97	15,98	- 80	+10	- 40	- 30	- 20
4'	216,61	301,75	151,92	119,95	15,95	- 90	+50	- 80	- 50	- 50
5	350,90	331,18	191,92	160,03	16,01	+100	- 20	- 80	+30	+10
5'	250,08	331,19	191,95	159,92	16,03	+80	- 10	- 50	- 80	+30
7	230,54	220,67	101,00	69,98	15,47	- 60	- 30	0	-20	-30
7'	230,59	220,75	100,93	69,98	15,46	- 10	+50	- 70	-20	-40
8	248,82	238,77	101,98	69,98	16,00	-80	-30	-20	-20	0
8'	248,86	238,84	101,93	69,97	16,01	-40	+40	-70	-30	+10
9	274,28	261,41	131,98	100,02	15,97	-120	+10	-20	+20	-30
9'	274,33	261,39	131,95	99,97	15,95	-70	-10	-50	-30	-50
10	301,80	287,00	151,91	120,02	15,93	-100	0	-90	+20	-70
10'	301,83	286,99	151,97	119,99	15,92	-70	-10	-30	-10	-80
11	331,31	316,49	151,97	119,97	15,99	-90	-10	-30	-30	-10
11'	331,33	316,45	151,95	119,94	16,03	-70	-50	-50	-60	+30
12	372,60	349,86	240,47	159,97	64,98	0	0	-30	-30	-20
12'	372,57	349,90	240,47	159,95	65,04	-30	+40	-30	-50	+40
6	372,60	368,52	50,50			0	+20	0		
6'	372,61	368,56	50,51			+10	+60	+10		

Figure 6. The table of "spasers" dimensions (mm) and its deviations (μm) after correction.

N	ΔA	ΔB	ΔH	ΔE	ΔG
1	+20	-40	+40	+20	-70
1'	-30	-20	0	-10	-10
1"	-20	-70	-20	-40	+10
2	-40	-20	+40	-30	+30
2'	0	+20	+50	-20	+40
2"	-40	-70	+30	-30	+30
3	-40	+10	+50	-70	+60
3'	-40	-30	+30	-20	+80
3"	-40	-80	+10	-90	-90
4	-40	-50	+50	-20	+20
4'	-80	-40	-10	+10	-20
4"	-70	0	-10	-40	+40
5	+30	+10	+80	+20	-50
5'	-70	-40	-20	-10	+40
5"	-60	-110	+20	-60	+50
6	-60	-40	-10		
6'	-130	-30	0		
6"	-130	-70	-20		
7	-50	-10	+40	-30	-10
7'	+20	-70	+10	-10	+10
7"	-10	-40	-10	-40	+20
8	+20	+10	+30	-80	+50
8'	-30	+20	-10	-30	+40
8"	-70	-60	0	-60	+60
9	-40	+40	+30	+20	-20
9'	-50	-30	-30	-40	-50
9"	-20	-70	+10	-30	-20
10	-20	-50	-20	-20	+10
10'	-70	-50	+20	-40	+40
10"	-100	-70	+20	-40	-40
11	0	-80	0	-80	+20
11'	-60	-40	-30	-30	+10
11"	-10	-90	-40	-50	-30
12					
12'	-120	-10	-20	-80	+30
12"	-150	-60	+30	-60	-50

Figure 7. The deviations of "spasers" dimensions produced at Kirov's Plant S.Petersburg 29.11.95 (t=12°C).

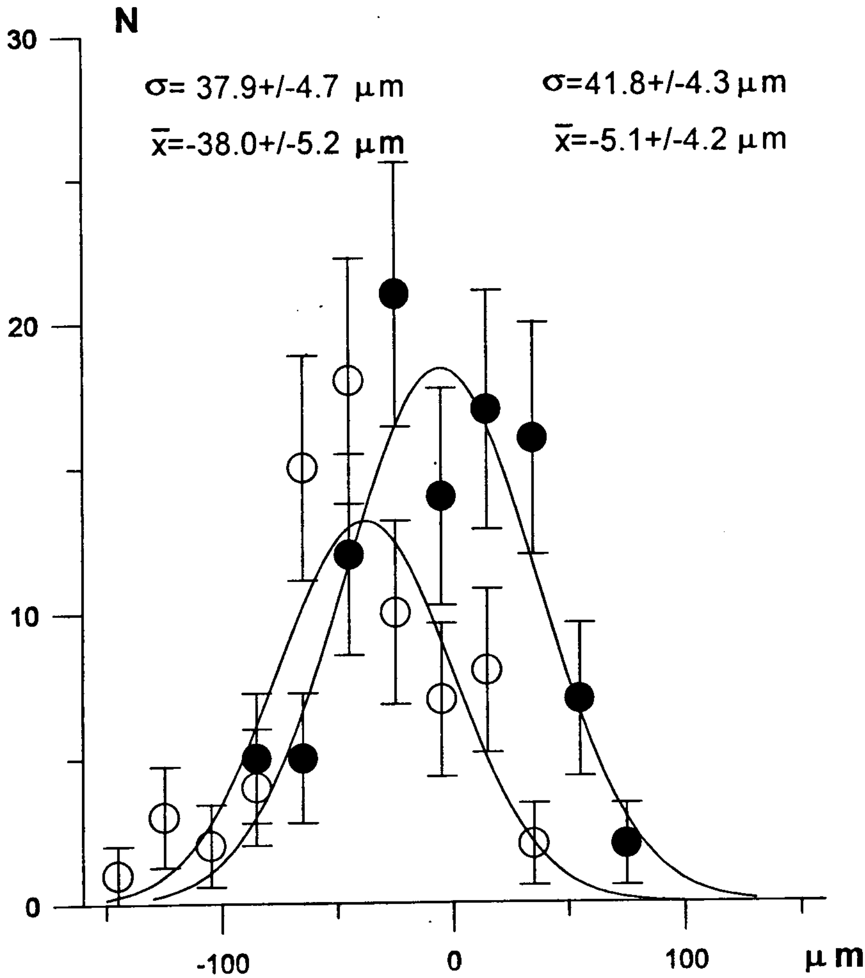

Figure 8. The distribution of deviations of real dimensions (fig.7.) from tabulated ones.

A,B parameters ○ H,E,G,g parameters ●

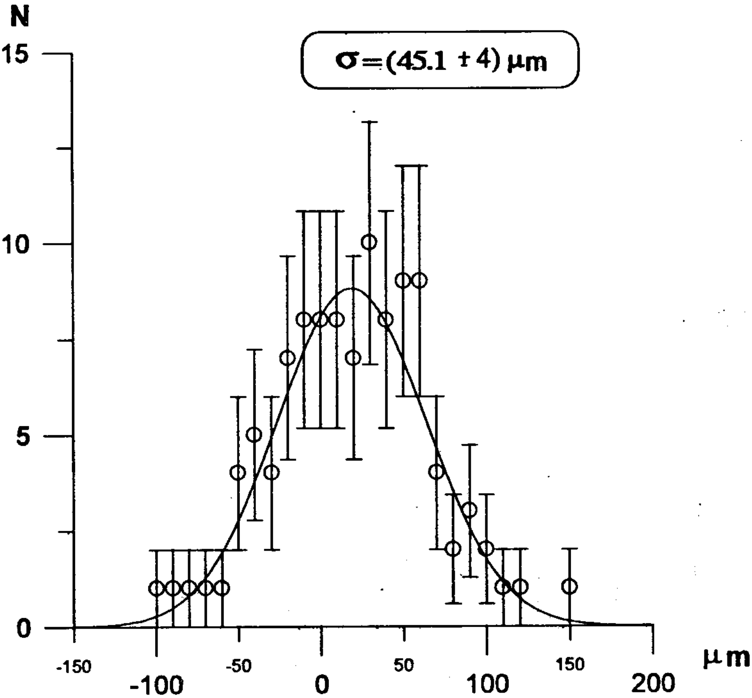

Figure 9. The ΔP - values distribution.

$\Delta P = dP_{1\ period} - dP_{j\ period}$; (j=2,3), dP=(dA, dB, dH, dE, dG)

Choosing of the Main Partner.

The "UNIVERSALMASH" plant is considered to be the basic manufacturer of the 0-module "spacers".

The RCTL RAS Shatura is remained as the first priority reserved one.

Other plants, mentioned above, are considered as potential manufacturers for 64 modules production. The corresponding quantities of master plates and of spacer plates are ≈45000 and ≈250000 respectively. Undoubtedly we need to have a few well prepared manufacturers to complete the cutting within the approved ATLAS schedule (i.e. for ≈1 year period).

We thank Marzio Nessi for numerous helpful discussions and creative help.

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Аликов Б.А. и др. E13-95-515
Последние достижения по прецизионному лазерному крою абсорберов адронного калориметра ATLAS

Описывается оптимизация технологии прецизионного лазерного кроя для получения необходимых параметров пластин-абсорберов адронного калориметра ATLAS. Представлены последние результаты обмеров пластин, изготовленных на заводе «Универсалмаш» (С.-Петербург) и НИЦТЛАН (Шатура). Показано, что реальная точность данных лазерных установок не хуже 45 мкм.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

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Alikov B.A. et al. E13-95-515
Recent Advances in Precision Laser Cutting for the ATLAS Hadron Calorimeter Absorbers Production

The optimised precision laser cutting technology for high tolerances ATLAS hadron calorimeter absorber plates production is described. Some recent results of laser cut absorber plates dimension measurements are presented. The plates have been manufactured by «Universalmash» (S.-Petersburg) and RCTL RAS (Shatura). It has been shown that the proved accuracy of the laser machines is not worse than 45 microns.

The investigation has been performed at the Laboratory of Nuclear Problems, JINR.

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