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Shielding block lug failures

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Shielding Block Lug Failures

Concrete blocks used for radiation shielding in the AGS experimental areas are transported and installed by lifting them by means of a steel lug imbedded into the concrete. Twice in the past, these steel lifting lugs have failed in use and an investigation has been conducted to determine the cause of these failures and to identify a course of action to prevent future failures.

The first failure occurred in the Target Building while lifting a B-block over the AGS ring. The block was raised to virtually the highest point possible with the crane and then a horizontal traverse was begun. At this point, the lug failed causing the block to fall onto the AGS roof.

The second failure occurred over the B cave in EEBA. Fifteen-foot roof beams were being lifted to expose the cave below. One beam was wedged between adjacent beams and, when lifting was attempted, became stuck with a tilted orientation. Further attempts to free the beam resulted in the lug breaking.

Following the failures, stress analysis and mechanical and physical testing of the lugs was carried out to determine the exact cause of the failures. It is estimated that 2344 shielding blocks are used in the AGS complex with a lug design similar to the failed blocks including 702 B-blocks and 59 fifteen-foot roof beams. A sketch of the two blocks that failed is shown in Fig. 1., and a detail of the lug is shown in Fig. 2.

Stress analysis was carried out to determine whether the loads imposed on the lugs were sufficient to cause failure. Hand calculations showed that for "ideal" vertical lifts and considering stress concentrations around the lifting hole, the tensile stresses imposed were about 22,000 psi for the two lugs. This is about one third of the ultimate tensile strength of the material, not enough to cause failure but certainly not a generous safety margin either. A finite element computer code called MESS (Mechanical Engineer's Stress) was used to analyze a two-dimensional model of the B-block lug. A representative view of the model and its exaggerated shape under loading is shown in Fig. 3. The results of this analysis showed the von Mise's (total) stresses in the lug at the point of failure were about 25,500 psi which is close to the hand calculated values.

Inspection of the lifting equipment following the B-block failure showed that a large clearance existed between the lug and the lifting fixture used and between the lug and the pin, which can be seen in Fig. 4. The figure shows how these large clearances permitted the lifting fixture to impose large bending forces on the lug during horizontal accelerations. Analysis showed that bending stresses of over 56000 psi could be imposed by an acceleration of only 1 ft/sec^2. These stresses are extremely high and could result in lug failure.

In addition to the stress calculations, several tests were conducted to determine the mechanical and metallurgical properties of the failed lug material. These tests were conducted by the BNL Metallurgy Department, the Analytical Chemistry Group in the BNL Hot Laboratory Division and an independent testing laboratory, Lucius Pitkin, Inc. of New York City. The tests included:

- Tensile Strength
- Yield Strength
- Elongation
- Reduction in Area
- Brinell Hardness
- Charpy Impact Strength
- Metallographic Examination
- Scanning Electron Microscope Examination
- Qualitative Spectrographic Analysis
- Quantitative Chemical Analysis

The results of the tests indicates that the failed lug material was very similar to ordinary mild carbon steel (tensile strength ~68000 psi, yield strength ~35000 psi) with one important exception: the notch toughness determined by the Charpy Impact test was unusually low. This indicates that the material has a high ductile-to-brittle transition temperature which means that at temperatures normally encountered by AGS shielding blocks, the lug may behave in a brittle fashion.

The results of the qualitative spectrographic and quantitative chemical analysis indicated that the material possesses an extremely low silicon and aluminum content indicating the material to be a rimmed (non-killed) steel. Non-killed steels inherently exhibit little or no toughness and this is consistent with the fact that a visual examination by metallurgical experts determined that the two lugs in question experienced a classical brittle failure.

It was not known to what extent other shielding blocks with the same lug design possessed non-killed steel so a random sampling of 52 blocks was conducted. The results are as follows:

Type of Steel	*Number of Samples*	*% of Total*
Killed	16	31
Semi-killed	12	23
Non-killed	24	46
	52	100

It is judged that this random sampling is indicative of the whole block population; therefore, approximately half of the blocks have low toughness steel and an additional one quarter have steel of moderate toughness. Clearly a solution to the lug failures would have to be applicable to all blocks.

The metallurgical and mechanical tests determined how well the lug material responded to the stresses imposed on it and the stress analysis determined, in a theoretical way, what the value of those stresses were. It was felt that a more complete understanding of the actual loads and stresses imposed on the lug was needed to identify solutions; therefore, measurements were made during actual shielding block handling operations so that a greater understanding of the lug performance could be gained. Two B-blocks were instrumented and tests were carried out by BNL and by Dayton T. Brown, an independent testing laboratory.

The instrumentation consisted of strain gages (by measuring strains one can infer stresses) and accelerometers which measure accelerations or shock loading imposed on the blocks. A complex matrix of tests were carried out in two experimental halls with different cranes and using an old style lifting fixture with and without clearance reducing parts and a newer, clamping lifting fixture. Variations of lifting speeds and accelerations and horizontal traverses with the crane hook at different heights were measured. It was found that some of the things that affected the measurements were:

a. Is the lifting fixture centered?
b. Is the lifting lug plumb?
c. How round is the lifting lug pin hole?
d. Is the lug located over the center of gravity of the block?

e. What are the individual characteristics of the crane operator?
f. What are the crane speed, brake characteristics, etc.?

Analysis of the data from the strain gage and accelerometer measurement yielded the following conclusions:

a. Accelerations change the most when just picking a block up or setting it down (1-2 g). For non-vertical accelerations this is most likely due to the lug not being plumb or located over the center of gravity.

b. Other lifting and motion changes resulted in accelerations of 0.2 to 0.3 g which is considered small.

c. Normal tensile stresses were measured at 20,000 to 30,000 psi.

d. Large stresses were encountered when moving one block horizontally against another (bashing).

e. Large stresses were encountered when using the old style lifting fixture with a small pin. These stresses were greatly reduced by using shims and a larger pin in the old fixture to reduce the excessive clearances. These stresses were reduced even more by using a new, clamping fixture. The old style lifting fixture can be seen in Fig. 5.

Analysis of all the test data (metallurgical, mechanical, strain gage and accelerometer) plus the results of the various tress analyses and site investigations of the failures has led to a good understanding of the two lug failures. The first failure appears to have been caused by the fact that the lifting fixture used to engage and pick up the shielding blocks by their lugs was very loose fitting. When the block in question was being traversed horizontally, the direction of the traverse was changed rapidly causing the block to shift its position in the lifting fixture and experience severe bending stresses which, when combined with its normal stresses, resulted in failure. The second failure occurred when a shielding block, which was wedged between two other blocks, was being pulled free. Excessive force was used on this block resulting in a severe overload and failure resulted. Once it was determined what caused the lug failures, potential solutions to the lug problem were identified, tested, and put into use. The three classes of solutions are:

1. Modify the way in which shielding blocks are handled.

2. Change equipment to reduce the stresses on the shielding block lugs.

3. Modify the shielding block lugs to give them a stronger design.

The first item was accomplished by changing the way in which the riggers handle the blocks. A thorough *Rigger Training Course* has been institute by Plant Engineering utilizing Bob DeBenedictins, Inc., a crane and rigging safety consultant. Regular updates of this course are planned.

The following general precautions will be followed by rigging crews handling all block and equipment in the Experimental Area at the AGS.

a. All personnel will stand away a distance of at least equal to the height of the pick.

b. No lifts shall be made over experimental or BNL equipment without prior approval.

c. Lift limits will be set on any blocks suspected of being jammed.

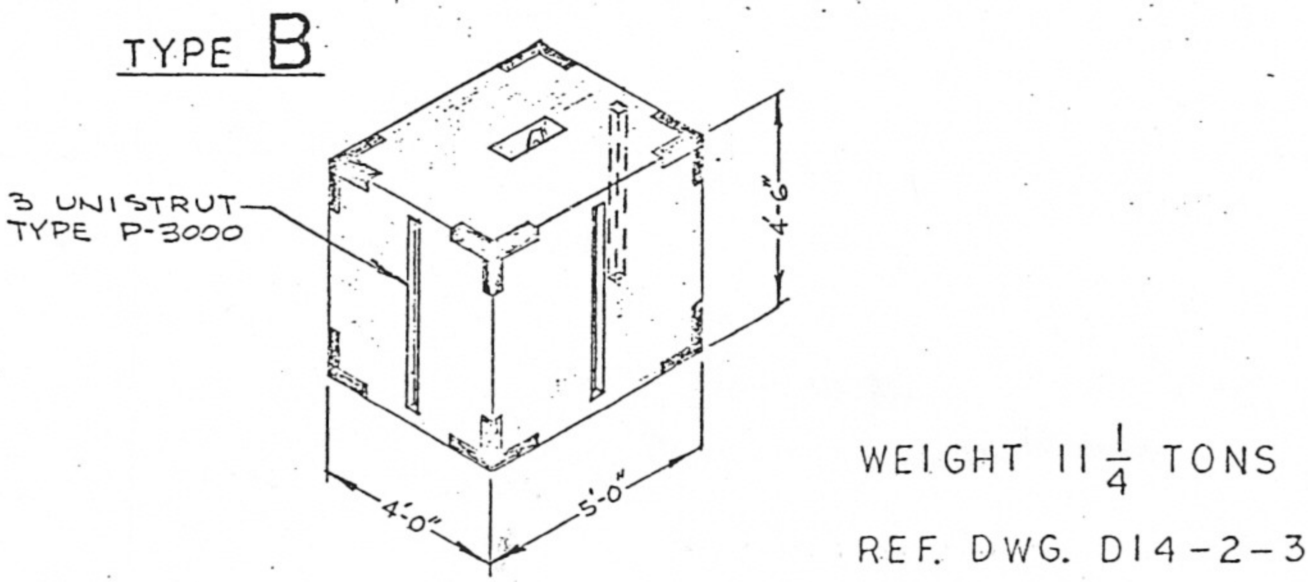
The riggers have taken a greater responsibility in preventing shielding block handling abuse and a greater level of care is evident in current block handling operations. Blocks of questionable safety are more readily identified and reviewed before handling is attempted.

The second item is being accomplished by making several hardware changes to reduce the stresses on the lugs. The large clearance problem evident in earlier lifting fixture, and a contribution to the first lug failure, has been eliminated by the use of spacers or shims as an interim measure. Since these shims must be installed each time a block is lifted (and thus could be forgotten), a passive type lifting fixture has been designed which will clamp the lugs in a manner which will transfer the bending stresses to an area of the lug which has sufficient strength to safely resist these bending stresses. Calculations show that this fixture reduces bending stresses by up to 50%. A prototype fixture has been built and tested and a full production design of a passive lifting fixture is currently being manufactured for each experimental area crane. A drawing of this new fixture can be seen in Fig. 6.

Another hardware change is taking place at the cranes themselves. Since the second lug failure resulted from an inability to determine and control the force exerted on the stuck block, load readout and limiting controls are being procured for each of the Experimental Area's cranes. The testing of such devices has already been accomplished on the new NEEBA crane and it is judged that they work quite well. Additionally, limiting and controlling the rate at which the cranes apply their forces to the lugs can further reduce the lug stresses. This can be accomplished by using Variable Frequency Controls (VFC) on the crane motors. In comparing VFC's with standard stepped motor controls, it was found that stresses on an instrumented block were reduced by a minimum of 28%. Qualitative examples of this reduced stress can be seen in Figs. 7 and 8. Figure 7A shows the strain (stress) of a lug during a slow lift suing an old style (stepped) crane control and Fig. 7B shows the strain using a Variable Frequency Control. Likewise, Fig. 8A shows the strain using the old style control during a fast lift and Fig. 8B shows the strain using the Variable Frequency Control. Speed controls, therefore, will be installed on all new crane motors and retrofitted on appropriate existing motors.

The third item deals with modifying the shielding block lugs themselves. Metallurgists have determined that there are no metallurgical processes which will strengthen the existing lug material. In addition, reinforcing the lugs by welding additional material to them was tried but this solution was rejected when it was determined that the reinforced blocks were, in many cases, less strong than those blocks which were not reinforced. It is judged that reinforcement is not necessary, however, since the other solutions described above are adequate to assure safe block handling.

At this time, the past failures of the shielding block lugs appear to be well understood and all practical measures are being taken to prevent future failures on the lugs. Handling methods have been modified to assure no extraordinary stresses are imposed on the lugs and ordinary tensile stresses have been reduced by 28% using crane controls and bending stresses reduced by 50% using a new style of lifting fixture.



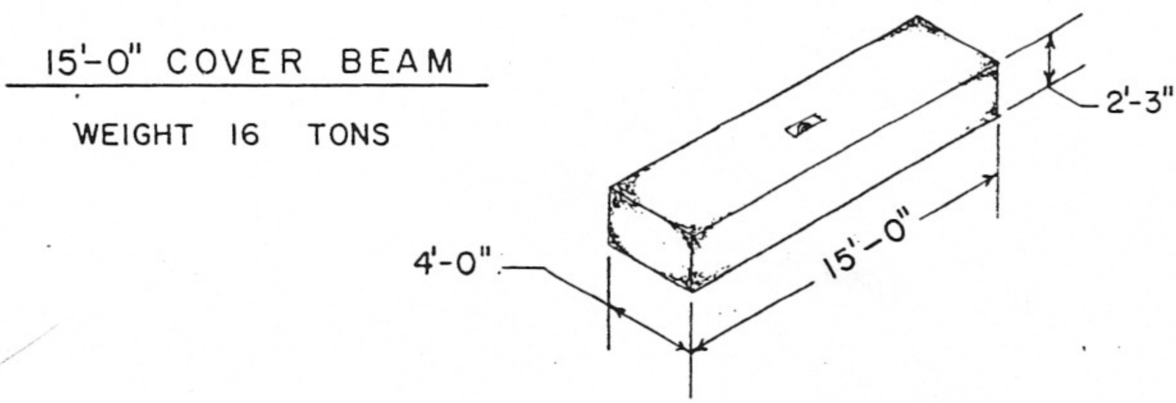
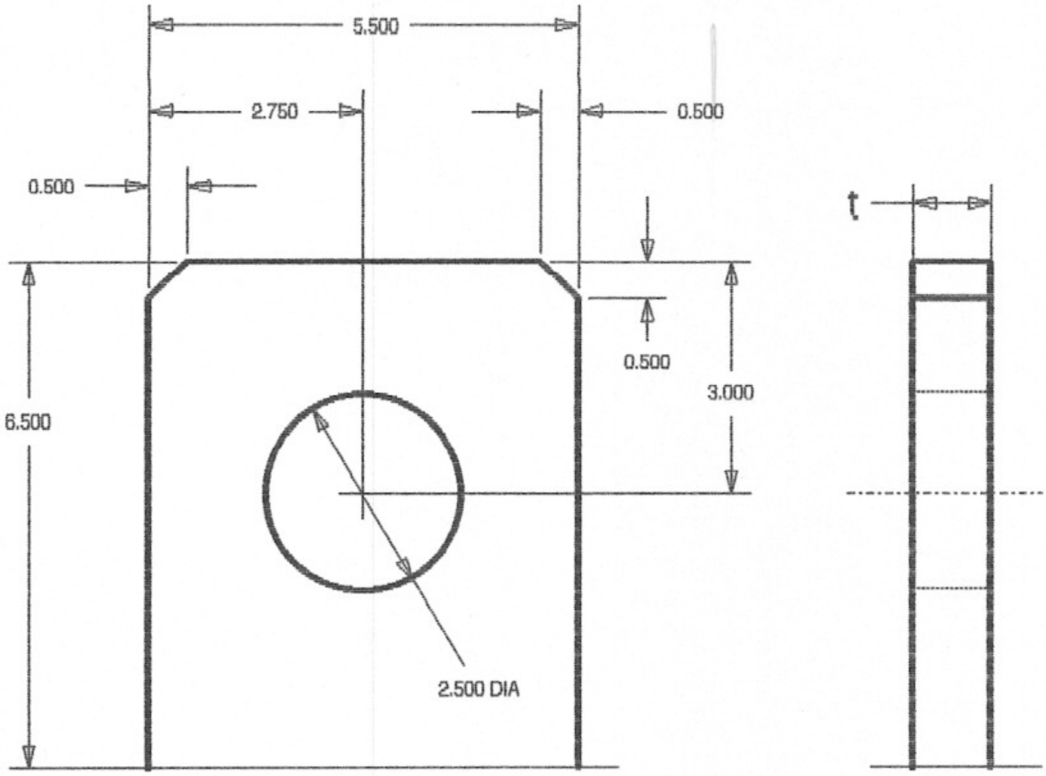


Fig. 1. Blocks that failed.

SHIELDING BLOCK LIFTING LUG



Block Name	t
15' Roof Beam	1.5
A	1.5
B	1.0
C	1.0
D	.75
E	.75
F	.75

Fig. 2. Shielding block lifting lug.

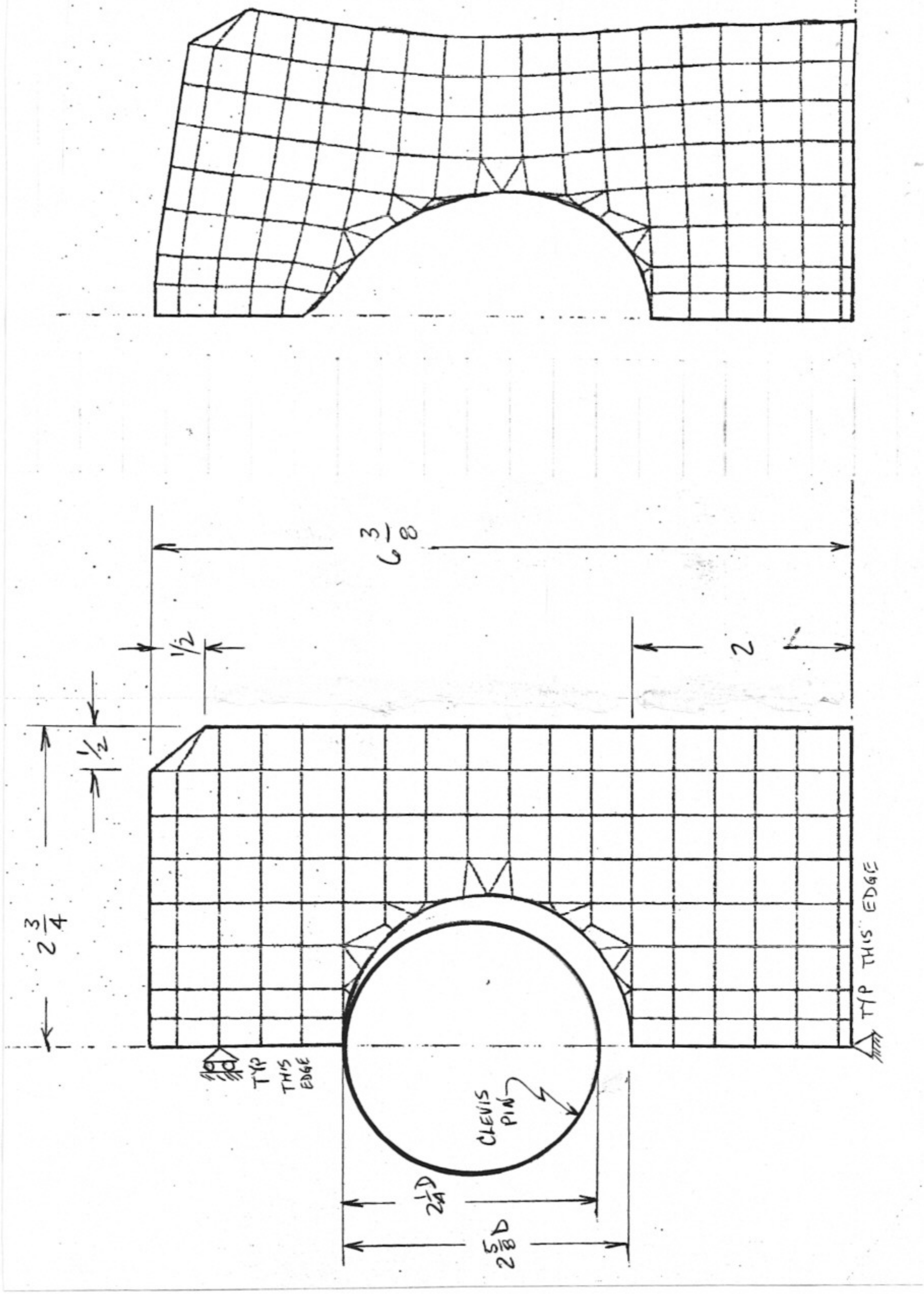


Fig. 3. Finite Element Model of lug and exaggerated model distortion under loading.

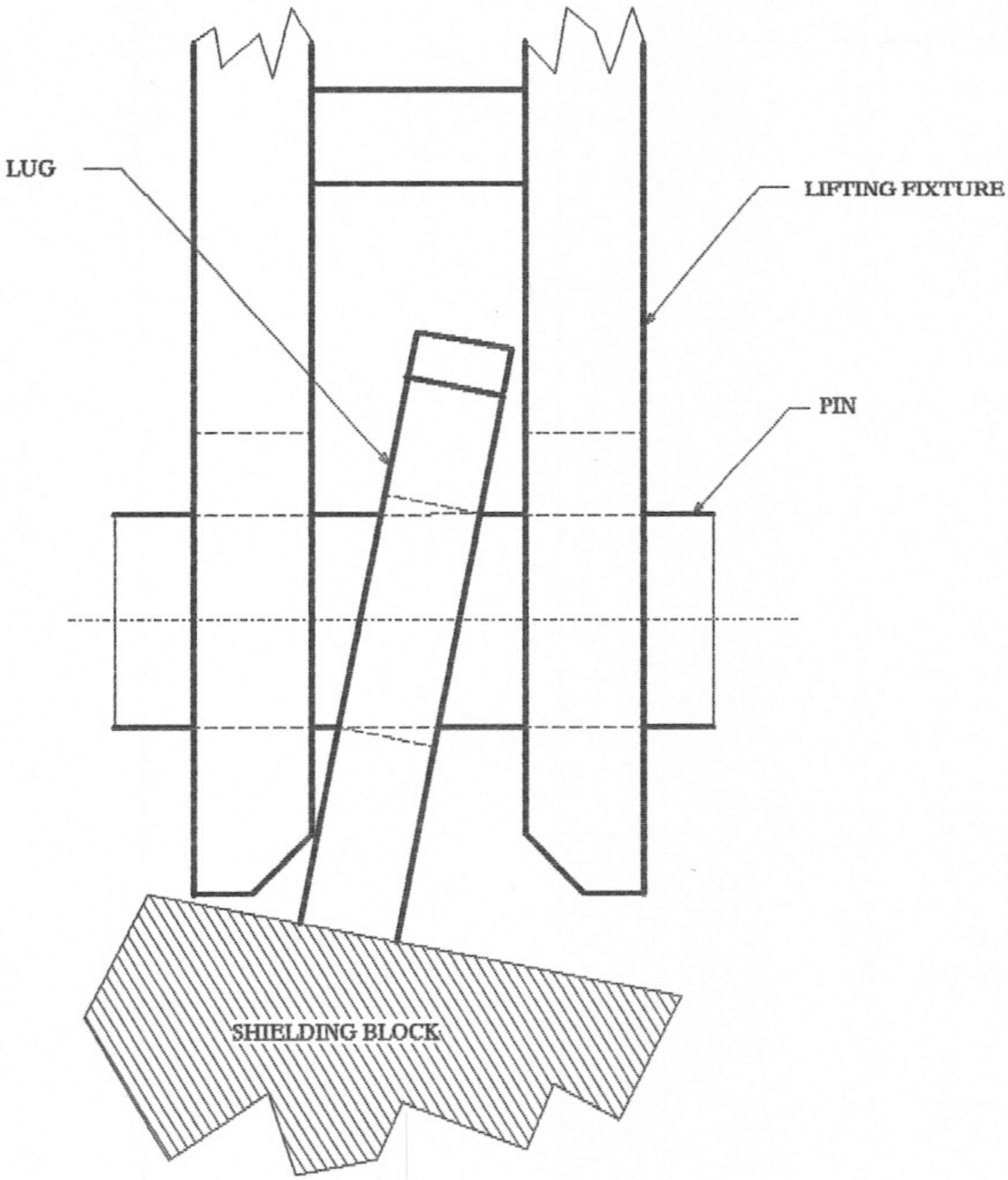


Fig. 4. Old style lifting fixture showing lug in bending.

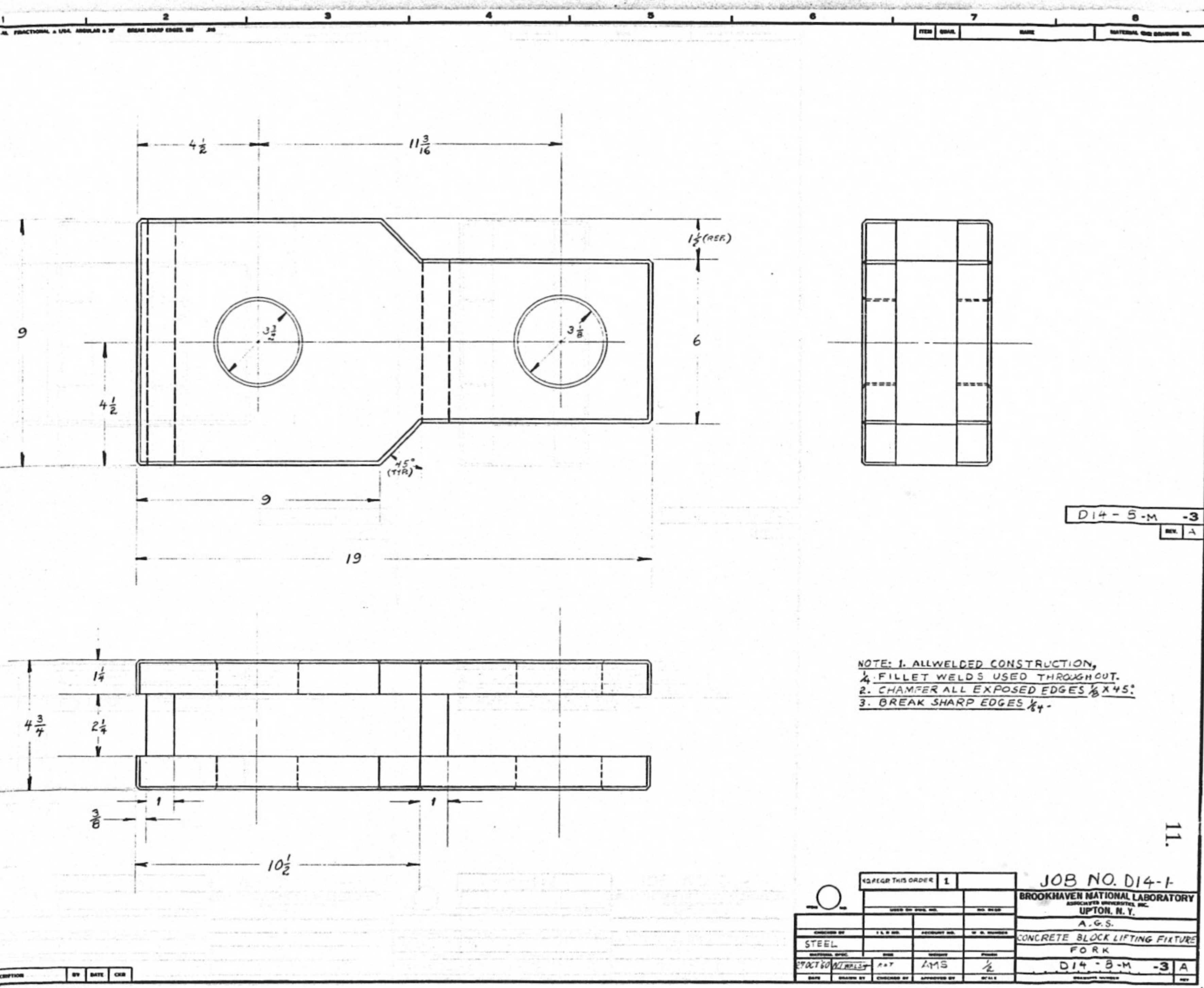
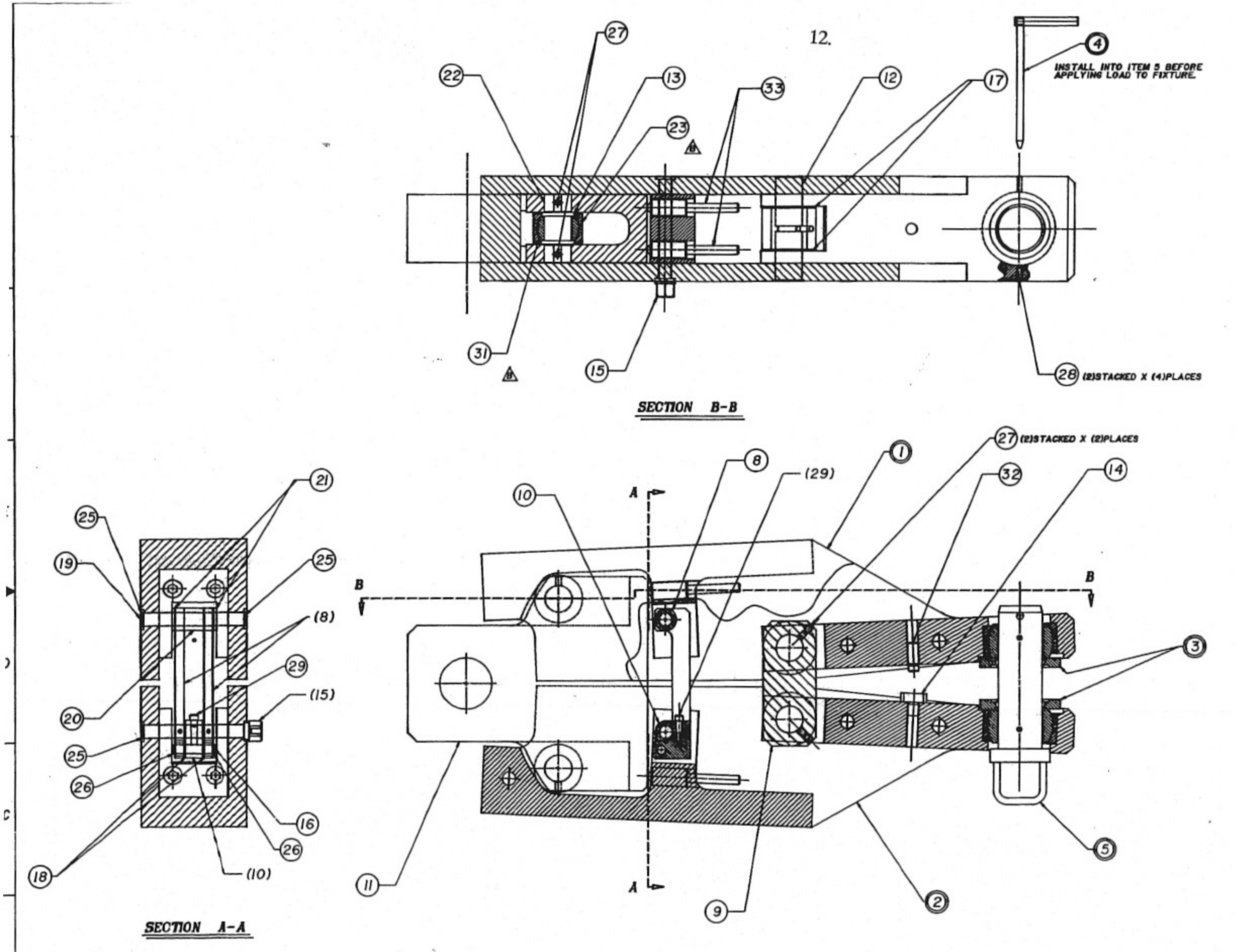


Fig. 5. Old style lifting fixture.



NO.	QTY.	DESCRIPTION	DWG. NO.
1	1	JAW #1 ASSEMBLY	D13-M-5861-5
2	1	JAW #2 ASSEMBLY	D13-M-5862-5
3	2	BEARING ASSEMBLY	D13-M-5895-3
4	1	"L" PIN ASSEMBLY	D13-M-5883-2
5	1	CLEVIS PIN ASSEMBLY	D13-M-5884-2
6			
7			
8	2	LINK	D13-M-5866-2
9	1	TIE BAR	D13-M-5867-2
10	1	CRANK	D13-M-5868-2
11	1	LIFTING PAD	D13-M-5869-4
12	2	MAIN PIN	D13-M-5878-2
13	4	BEARING WASHER	D13-M-5879-2
14	1	ANVIL	D13-M-5880-2
15	1	CRANK SHAFT	D13-M-5881-2
16	1	SHAFT	D13-M-5882-2
17	4	WASHER #1	D13-M-5885-2
18	2	WASHER #2	D13-M-5886-2
19	1	SHAFT	D13-M-5887-2
20	1	SPACER #1	D13-M-5892-2
21	2	SPACER #2	D13-M-5893-2
22	2	BEARING PIN	D13-M-5894-2
23	2	LIFTING PAD BEARING	D13-M-5928-2
24			
25	3	RETAINING RING EXT. 3/4 DIA.	H-39720
26	2	RETAINING RING EXT. 1/2 DIA.	H-39700
27	8	SETSCREW 5/16-18 X 1/2"LG.STL	T-62900
28	8	SETSCREW 1/4-20 X 1/2"LG.STL	T-62756
29	1	SCR.SOC.HD.CAP.5/16-18 X 1 1/4"LG STL	T-16684
30			
31	2	INNER RACE "MORSE"SPHERECO	BH-24LS
32	1	SWIVEL PAD CLAMP 5/8-11 "VLIER"	SC-351
33	4	PLUNGER 1"-8 "VLIER"	HH-1015

Fig. 6. New clamping lifting fixture.

B | F2,86 | ADDED ITEMS 23,31. ITEM 3 WAS D13-M-5863-3 | JAS

CADDS PART NAME: AGS.JAS.D13-0M-107.5870-5

D13-0M-107 – 1
BROOKHAVEN NATIONAL LABORATORY
UPTON, N.Y. 11973
A.G.S. GEN. EXPER. EQUIPMENT
SHIELDING BLOCK LIFTING FIXTURE
ASSEMBLY
D13-M-5870-5 B
11/28/88 | JASCHEBLEIN | BD | BD | HALF
1 CV/SUN

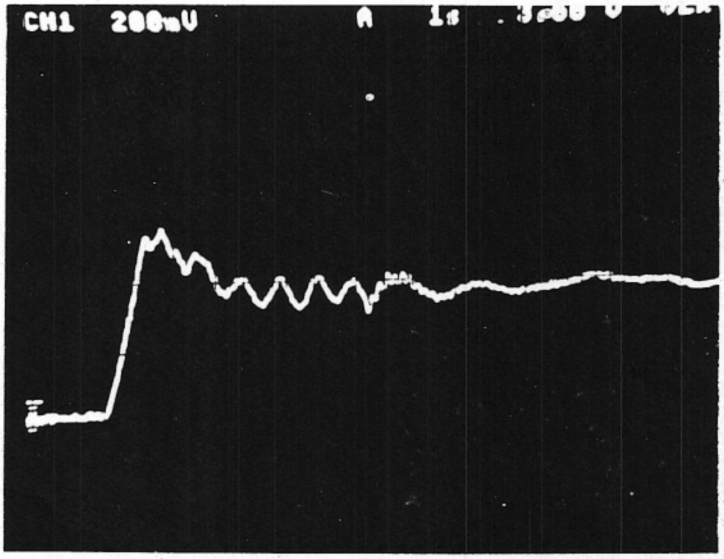


Fig. 7A. Lug strain during slow lift with stepped motor control.

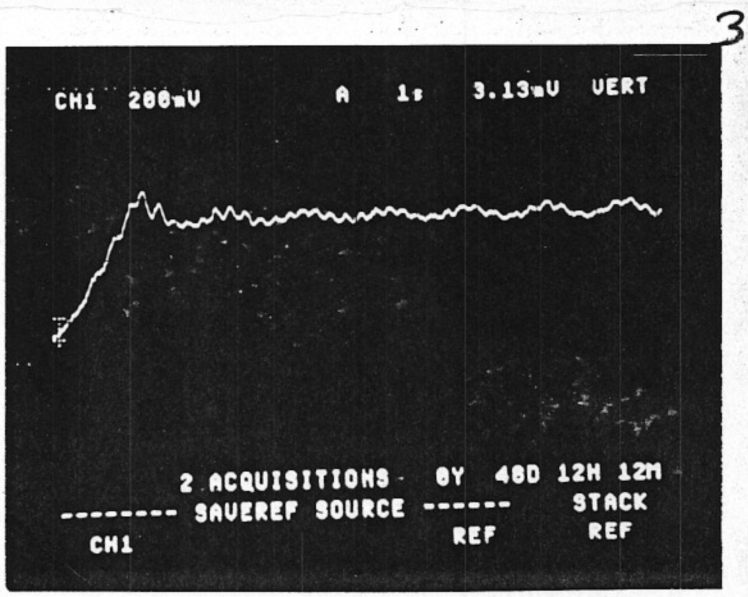


Fig. 7B. Lug strain during slow lift with Variable Frequency Control.

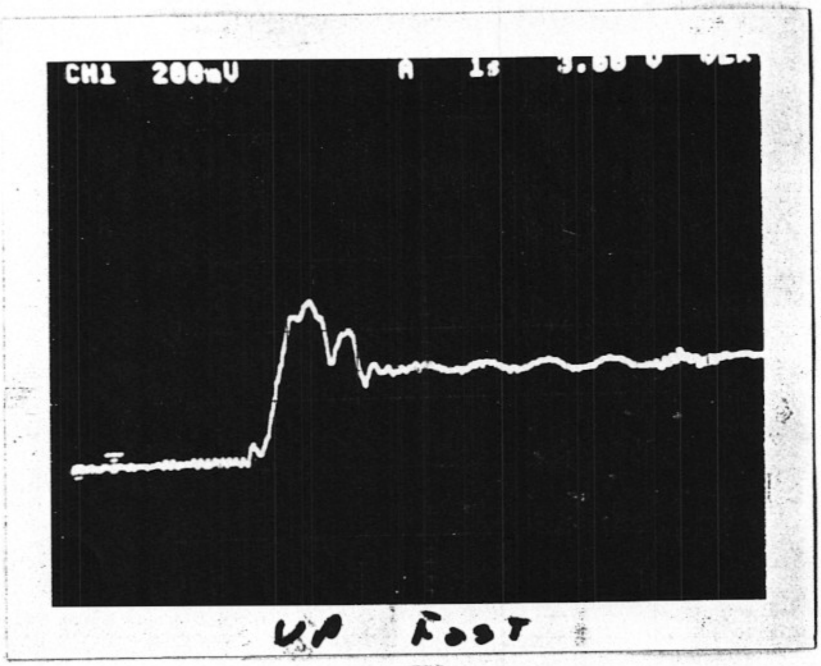


Fig. 8A. Lug strain during fast lift with stepped motor control.

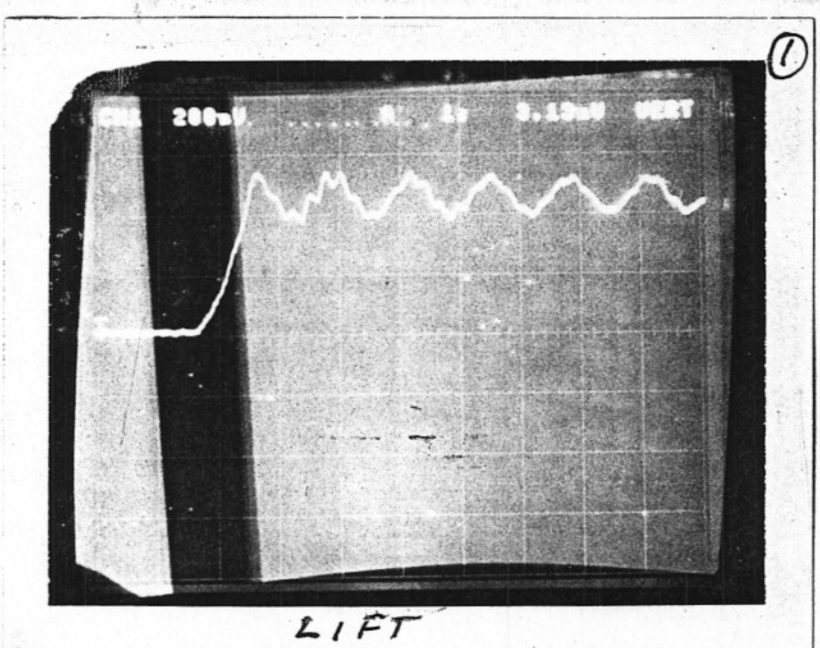


Fig. 8B. Lug strain during fast lift with Variable Frequency Control.