PERFORMANCE OF THE ZERO GRADIENT SYNCHROTRON AT ARGONNE NATIONAL LABORATORY*

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During the past two years, the capabilities of the Zero Gradient Synchrotron at Argonne National Laboratory have continued to be developed and expanded to provide maximum efficiency and stable conditions for our expanding high energy physics program. An aggressive machine research program is continuing in parallel with the development of new and novel diagnostic devices.

The scheduled machine time for the past two years is shown in Fig. 1. The time actually available for high energy physics experiments has increased from an average of 500 hours per month to 600 hours per month during this period, and the efficiency of operation has increased from 80% to 90%.

For the past year, machine research time has been scheduled only after a machine research experiment is written, discussed, and then approved by the Division Director. This has resulted in more efficient use of time scheduled for machine research. The results of each experiment must be submitted to the Division Director and discussed at regularly scheduled seminars.

Scheduled maintenance time during this period has decreased from an average of 10% to 6% of the total scheduled time and 75% of the routine maintenance is now scheduled by computer.

The average beam intensity during the past two years has increased from 4×10^{11} to 2×10^{12} protons per pulse with a recorded maximum intensity of 2.6×10^{12} protons per pulse. This increase was the result of an improved vertical damper, injection into nonaccelerating buckets, the installation of correction windings installed on the magnetic end guards of the main magnet, and, in no small part, the continuous effort of the operating crew to find the best tuning conditions and the optimum beam steering program.

The attitude and morale of the operating crew is extremely good. They spend approximately 50% of their time in the laboratory on development work, and we continuously attempt to improve their knowledge of the machine and in their discipline by regularly scheduled training sessions. A closed circuit TV system on which assigned staff members regularly conduct training sessions on all three shifts, links four control rooms, and programmed learning texts covering a variety of subjects are given to crew members for studying outside working hours. These efforts have resulted in competent and interested operating crews.

The stability of the accelerated beam does vary throughout the operating period for reasons not completely understood. On a good average day, intensity variations will be on the order of 5% as shown in the histogram of Fig. 2. On a bad day, this variation will increase to as high as 15%. The ZGS beam efficiencies are shown in Fig. 3.

The present operating schedule is as shown in Fig. 4 and provides for approximately 94% of total scheduled time for HEP or machine research. In scheduling HEP experiments, it is assumed the machine will operate 90% efficient at a beam intensity of 2×10^{12} protons per pulse.

Both swing target manipulators operating from the side of the vacuum chamber and flip targets operating from the bottom of the chamber are used for spill to the meson beam lines. Both manipulators are fully adjustable for target position and angle.

Slow beam spills are controlled by measuring the rate of secondary particles and feeding this back to the rf frequency program to maintain a constant spill rate. Four independently controlled slow spill rates can be provided by the control equipment and a constant spill time independent of intensity is also available.

Fast spills are obtained by rf programming (~ 800 μsec) or a fast magnetic bump (50 μsec) and feedback from the experimenter can be used to terminate either fast or slow spills. A typical program of four experiments operating within one pulse is shown in Fig. 5.

The dual purpose target has been used continuously during the past two years to provide simultaneous slow spill to both the meson beam lines and to the external proton line. The yield to the meson beam lines is reduced by about 30% using this technique, compared to using a target designed exclusively for meson production, but the extraction efficiency is normal.

During this period, a new extraction technique, suggested by Dr. S. Suwa of Argonne, was tested and provided an extraction efficiency of 55% for fast spills. In this scheme, a magnetic bump is used to increase the amplitude of betatron oscillations until the beam hits an outside energy loss target and then jumps into the extraction magnet system.

Many different magnet programs have been used on the ZGS during these past two years. Figure 6 indicates the range of values used in typical programs. The longest flat-top we have used is 1.1 seconds which provides a 20% duty factor on spill, and we believe this can be extended. One experiment completed during this period, as well as a similar one now in progress, required a slow extracted beam spill at thirty-five different energies between 5 GeV and 12.5 GeV. This was provided by changing the field at which the front porch occurred in the magnet program approximately every eight hours. Each change of field required approximately ten minutes, and was accomplished without disturbing the flat-top spill programs.

The front porch and flat-top programs are obtained by programming the firing angles of the main rectifiers and trimming the firing angle adjustment with a fast analog $\dot{B}$ feedback loop. A computer program used for properly setting the firing angles on the front porch and flat-top allows any magnet program to be set up within ten minutes.

The major problems requiring attention on the ZGS are the vertical and radial beam instabilities at high intensities, radiation damage to synchrotron components, and adjusting the high energy tune to increase the useful aperture.

The vertical damper, which is required to accelerate beams larger than 4×10^{11}, can handle intensities up to approximately 2.5×10^{12}. Above this intensity, the common mode signal causes the system to saturate, with subsequent loss of beam. Work is continuing on improving the common mode rejection bandwidth which must be effective to higher than 50 megacycles. Techniques are being investigated to simplify the overall system, and to perfect a digital system presently being developed.

During the early steering program, some resonances must be crossed, and a poor program can cause a beam loss of 90% due to radial instabilities. A good steering program results in a beam approximately 6 inches wide at full energy for 2×10^{12} protons. The nondestructive beam profile monitors described in an earlier session have proven invaluable in determining the best steering program. The installation of pole face windings should reduce this problem.

Radiation damage has been most severe on the epoxy filled, stainless steel spacemetal, inner vacuum chamber on the ZGS. During the past nine months, at the location of the targets on the downstream end of octant 4, many blisters have formed and were repaired on the inner skin of the chamber. These seem to be caused by gas generated in the irradiated epoxy and recently a grid of holes has been drilled on the inner skin to allow gas to escape before forming blisters. The effectiveness of this technique has not yet been determined, but in any case, we are confident we can continue to operate at full intensity until the installation of new all metal, titanium vacuum chambers next year.

The general radiation level background in the Ring Building during a typical maintenance period is from a few millirads to 25 millirads per hour. Inside the vacuum boxes, the level is from 0.5 to 6 rads per hour in the targeting straight section, and as high as 15 rads per hour at the first extraction magnet.

*Work performed under the auspices of the U. S. Atomic Energy Commission.

Radiation damage to other components of the machine has not been so severe, although it has shortened the life of target manipulators, and requires regular patching of the vacuum seals in both the magnet and the rf cavity. A spare cavity with improved seals is now under construction.

A major ZGS improvement scheduled for next year is the installation of a new titanium inner vacuum chamber equipped with pole face windings. This chamber, shown in Fig. 7, is a rectangular titanium box with a skin thickness of 0.014 inches and strengthened on the top and bottom with diffusion bonded T bars. This chamber can handle 30 mm of pressure without restricting the aperture and it can completely recover from pressures as high as one half atmosphere.

The resistivity of this chamber will be approximately seventeen times greater than the present chamber, thus increasing the vertical instability growth rate by a factor of four. This will be compensated for by using the pole face windings to raise the threshold of instability. Figure 8 shows a test section of the new chamber.

A prechopper, operating at the synchrotron injection frequency, has been installed at the low energy end of the linac. Initial tests indicate this equipment reduces the linac tank loading by 50% and makes an appreciable difference in the Ring Building radiation level, without decreasing the accelerated intensity.

A 50 MeV beam chopper is under construction and will be installed in the high energy end of the linac to aid in injection studies.

The linac debuncher is now equipped with its own amplifier which will allow programming the debuncher rf phase angle, with respect to the main tank, during the injection pulse. This will allow modulation of the beam injection energy and, hopefully, increase the intensity of the accelerated beam. A double reentrant short accelerating column has been designed and is in the final stages of assembly.

Development of the accelerated beam position and profile measurement systems will continue with the hope of being able to increase the bandwidth of the systems so as to be able to detect the coherent betatron oscillations. A three-dimensional display of the accelerated beam position and profile at any selected time interval is also planned.

A targeting cavity is being designed to provide more rapid beam manipulations which will be required when multipulsing more than one bubble chamber each magnet pulse. The synchrotron's Control Data 924 monitoring computer will be equipped with an executive program in the near future and it will then be used "on-line" for continuously monitoring the parameters of the machine and for controlling multiple spills according to a preselected priority program.

FIG 1

ZGS SCHEDULED TIME

FROM 4th QUARTER 1965 TO 3rd QUARTER 1967

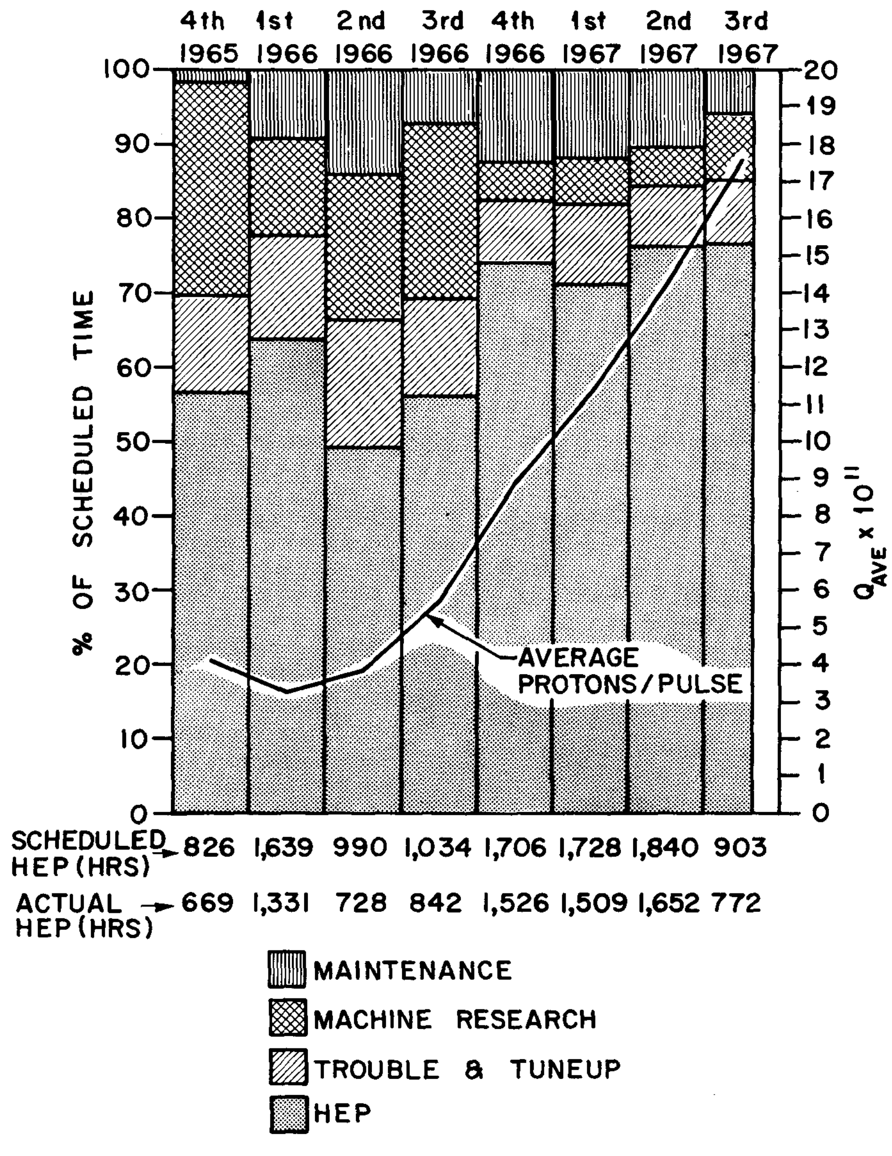


FIG 2

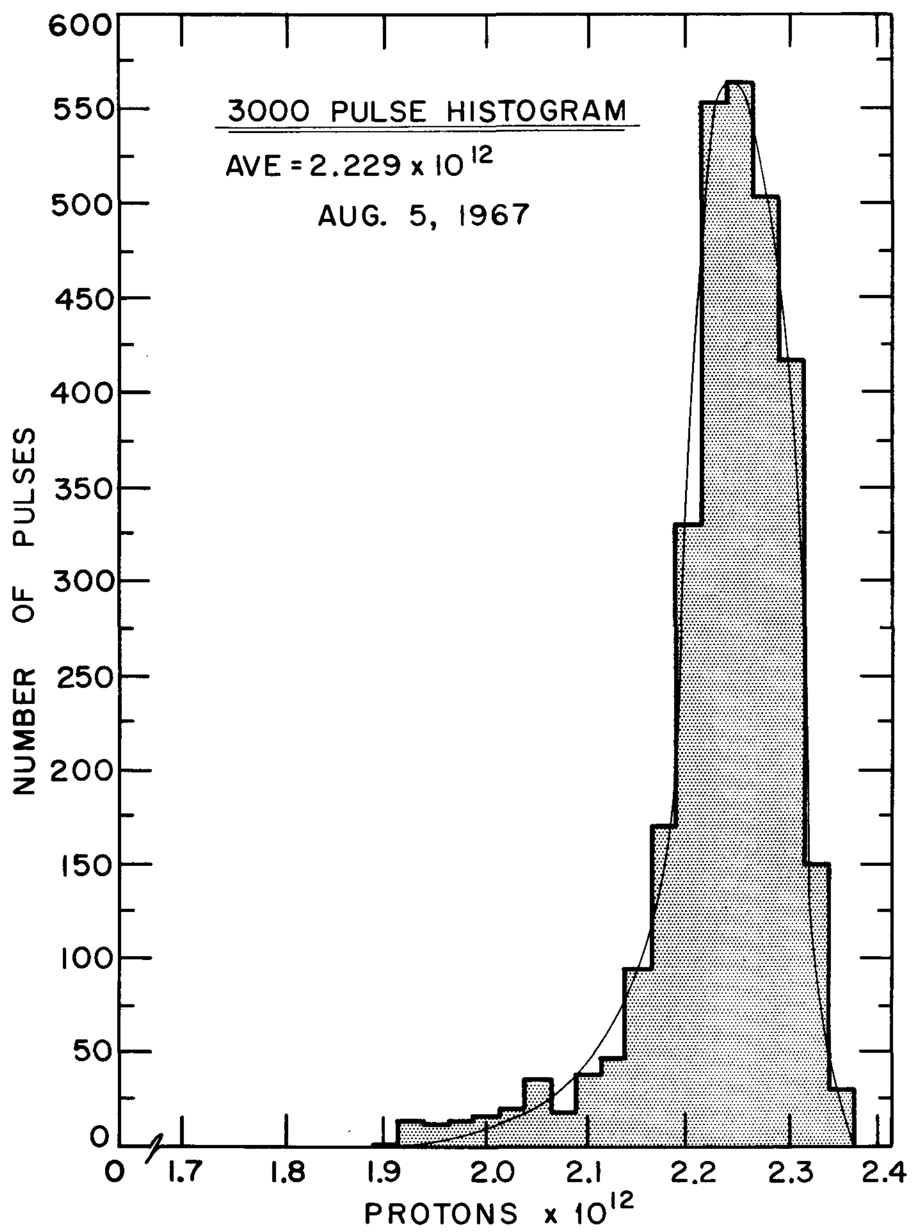


FIG 3

ZGS BEAM EFFICIENCY

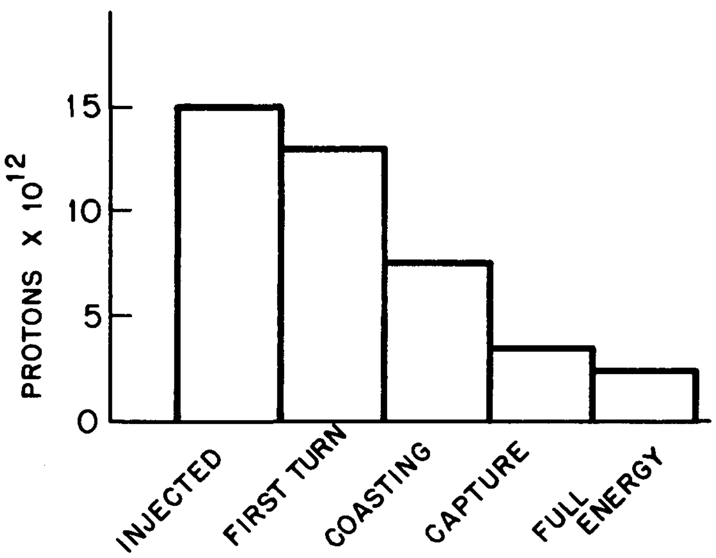
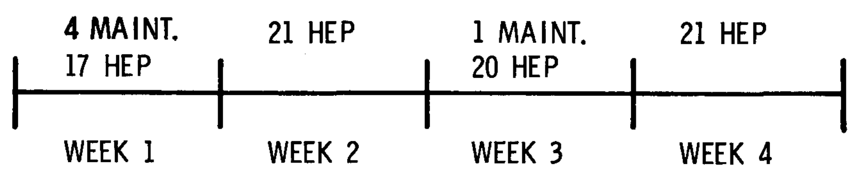


FIG 4

ZGS OPERATING SCHEDULE



5 SHIFTS MAINTENANCE (6%)
79 SHIFTS HEP OR MACHINE RESEARCH (94%)

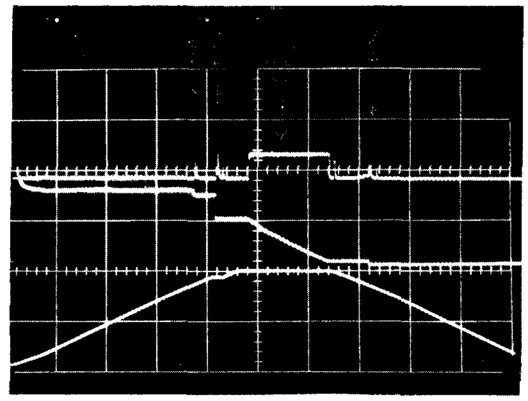


FIG 5

TYPICAL MONITORING SIGNALS FOR A ZGS PROGRAM

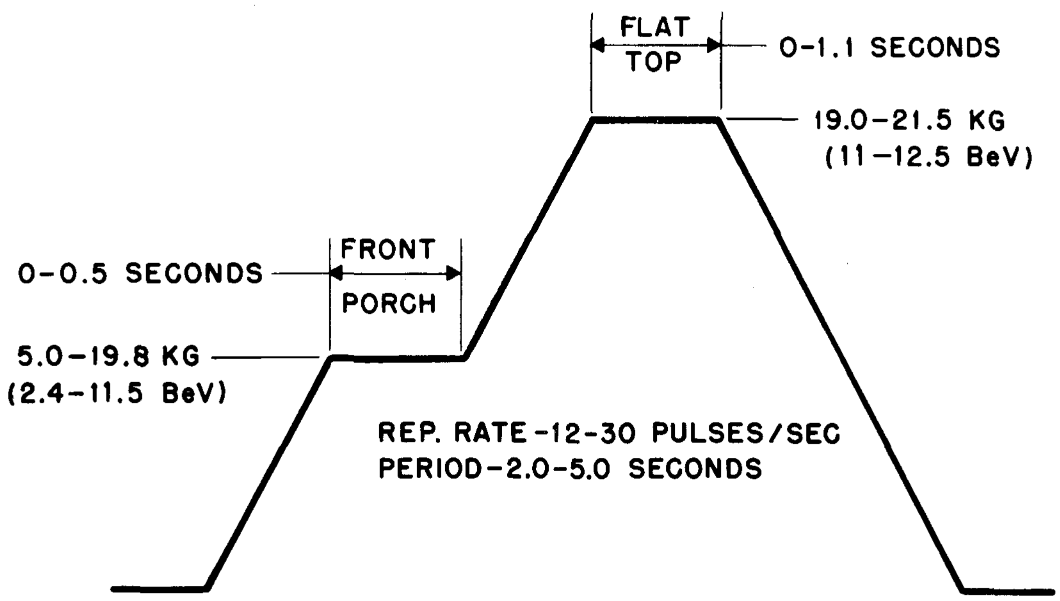


FIG 6

RANGE OF ZGS PROGRAMS USED IN THE PERIOD OCT 1965 — SEPT 1967

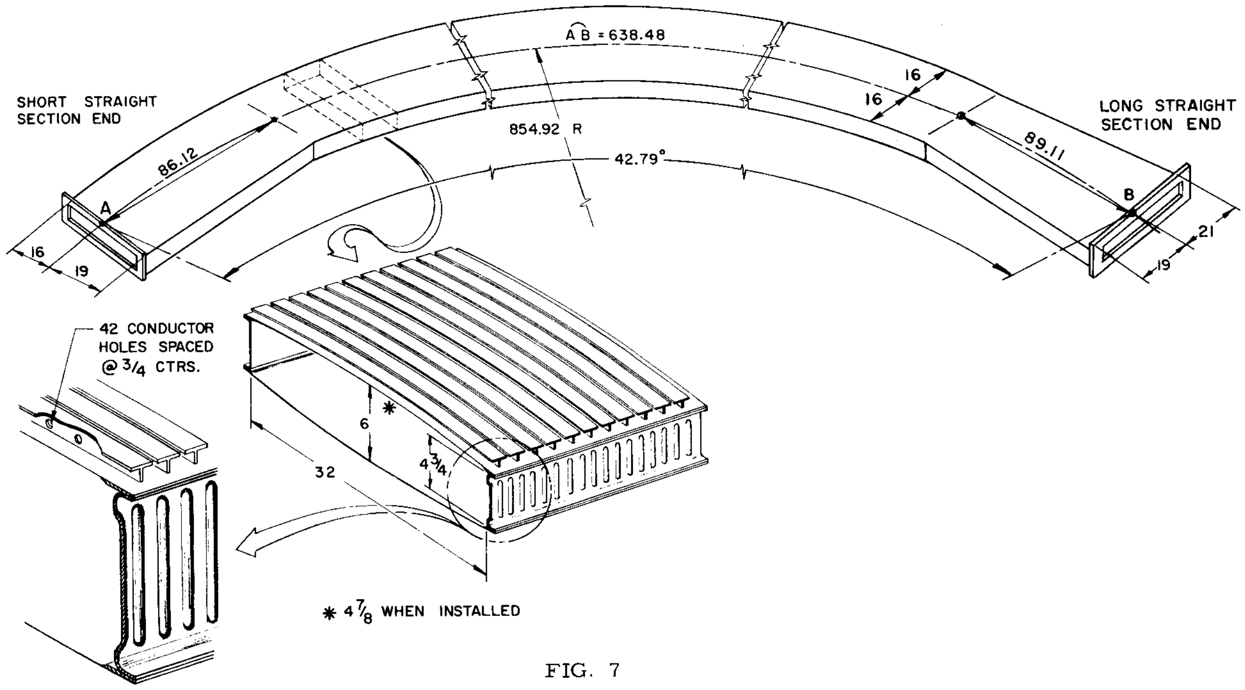


FIG. 7

ALL METAL-(TITANIUM) INNER VACUUM CHAMBER

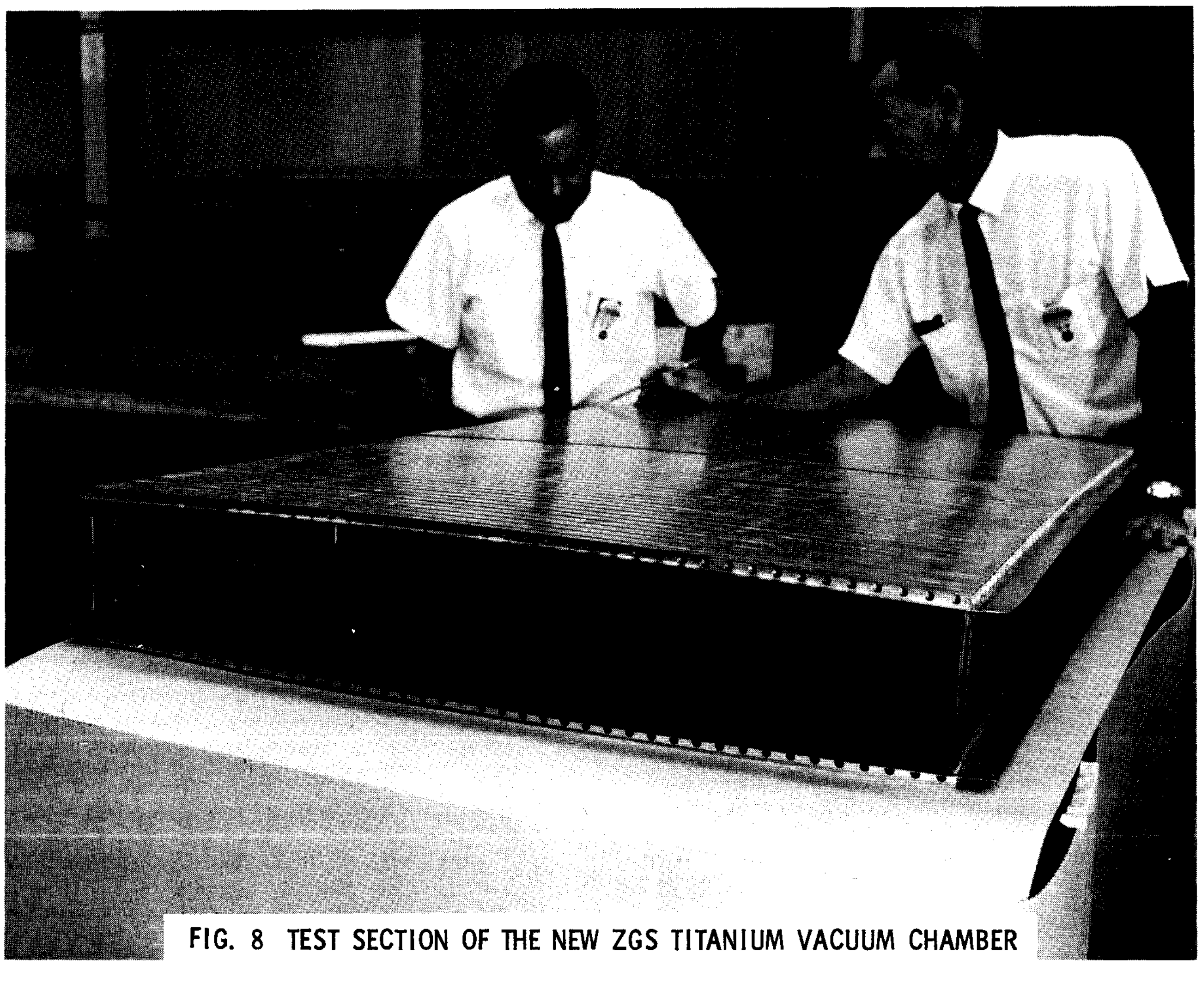


FIG. 8 TEST SECTION OF THE NEW ZGS TITANIUM VACUUM CHAMBER