WVT-TR-76020

AD

FEASIBILITY STUDY OF FILAMENT WOUND COMPOSITE ROAD WHEEL

JUNE 1976

U S ARMY ARMAMENT COMMAND

BENET WEAPONS LABORATORY
WATERVLIET ARSENAL
WATERVLIET, N.Y. 12189

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The feasibility of fabricating a M113 composite road wheel by the filament winding process has been demonstrated. Theoretical results, showing road wheel deformation where subjected to a radial compression load, have been obtained for both the conventional and composite M113 road wheel. Experimental results, for radial compression tests, show correlation between theory and experiment. Concepts for reducing road wheel vulnerability to mine blasts are also presented.

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FEASIBILITY STUDY OF FILAMENT WOUND COMPOSITE ROAD WHEEL

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Cont)

LIST OF TABLES

INTRODUCTION

The road wheel study provides a convincing demonstration of the broad utility of filamentary composites. Although the original objective of this work was to minimize or reduce conventional road wheel weight, it seems that the use of composites might also reduce road wheel vulnerability to mine blast effects. The Watervliet Arsenal's proposal to TACOM was made October 1974, followed by a visit from Mr. R. Siorek (TACOM) on April 7, 1975, and actually funded 7 August 1975.

The April 7, 1975 meeting with Mr. R. Siorek produced the following recommendations:

1. It was felt that every effort should be made to start an organized R&E effort in developing a lightweight composite road wheel choosing as a model the M113 wheel.
2. A two year plan was tentatively sketched.
   a. <u>1st Year</u>:

      Phase I: Preparation of a design

      II: Fabrication of three prototypes

      III: Limited in-house testing

      IV: In-house testing at TACOM which would include:

      a. Static and Rolling Loads
      b. Impact Tests
      c. Drum Endurance Tests
      d. Side-Load Tests

b. <u>2nd Year</u>: (Upon successful completion of first year phases)

Phase I: Fabrication of a full set of road wheels plus spares (a total of 26 wheels)

Phase II: Field test which would include

a. Endurance
b. Performance
c. Noise
d. Vibration
e. Cold Tests

This report presents the first attempt in the design, fabrication, and testing of the Fiberglass/Epoxy composite road wheel depicted in Figures 1 and 2. The work accomplished is reported as follows:

I. Theory
  a. Analysis of the conventional M113 road wheel
  b. Analysis of the proposed composite wheel

II. Fabrication

III. Testing

  Static test results for
  a. M113 road wheel
  b. Glass/Epoxy wheel

IV. Conclusions and Recommendations

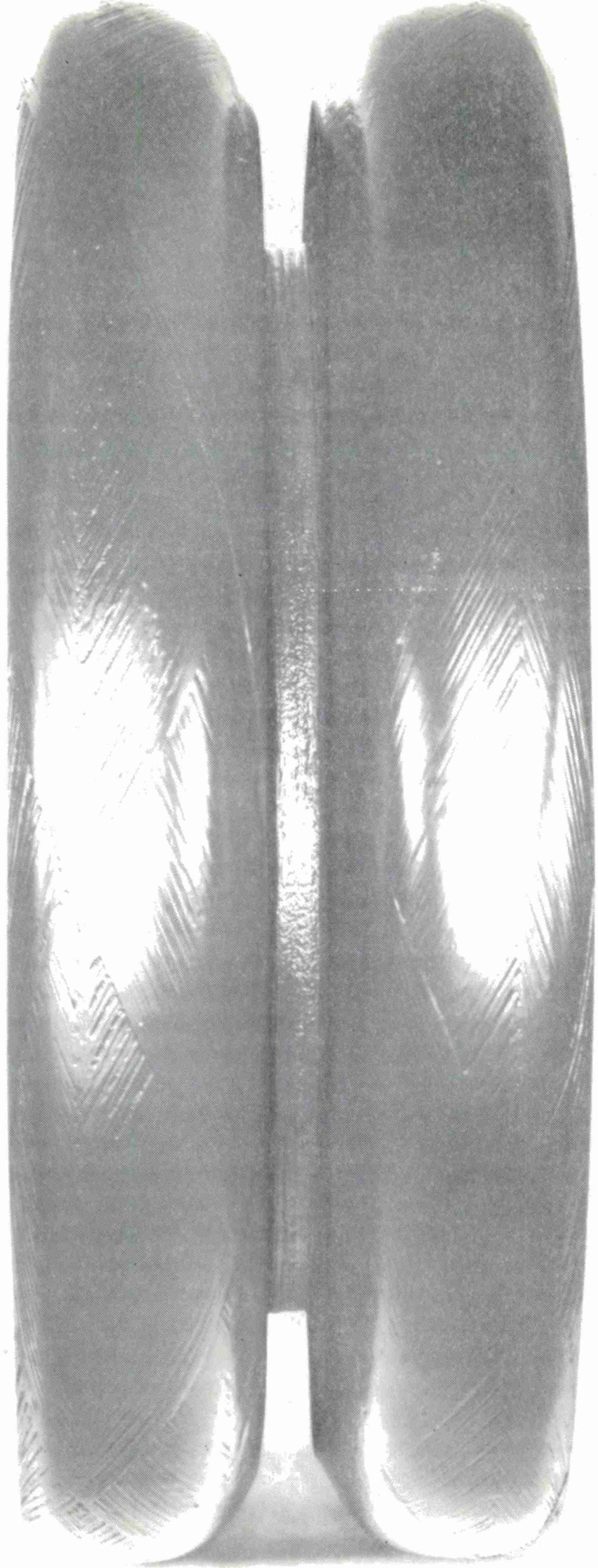

Figure 1. Front view of prototype composite road wheel.

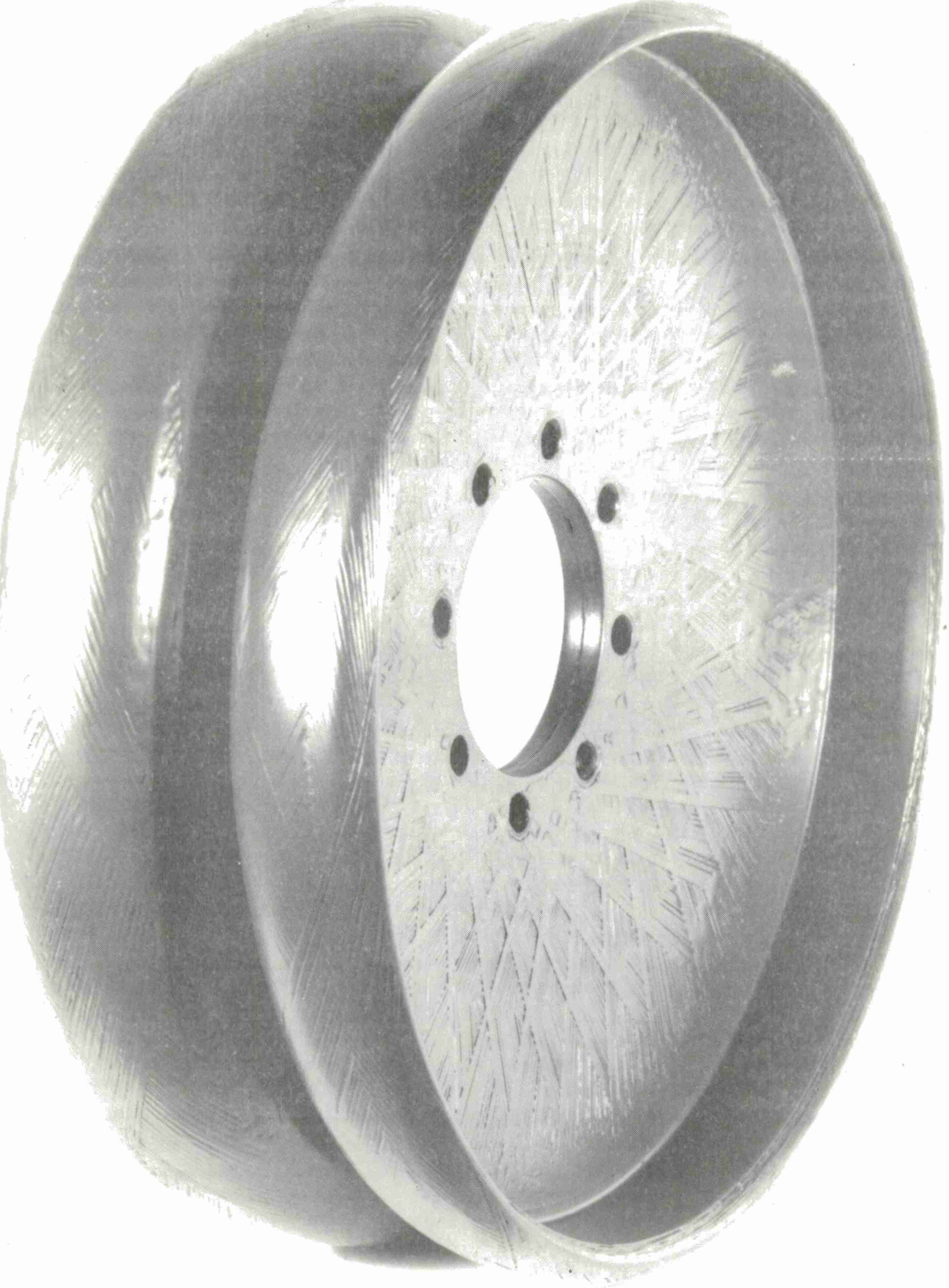

Figure 2. Side view of prototype composite road wheel.

I. THEORY

The theoretical modeling of the composite road wheel has been accomplished by the use of NASTRAN finite element system. The structure, characterized as an axisymmetric, anisotropic shell with non-symmetric loads, is analyzed by using the triangular membrane and bending plate element (CTRIA1) with transferse shear included. To test the theoretical procedure, and to provide a basis for comparison, the standard aluminum M113 road wheel was analyzed, and a simple experiment was performed on both configurations.

The rather limited project comprises primarily a comparative study, with some simplifying assumptions:

a. The rubber tire and wear ring were not included in the analysis.

b. Only one disk was considered.

c. Only a simple diametrical compression load was used.

The two finite element grids needed for the analysis were generated for one fourth (1/4) of each wheel using the program SGEN. These two grids both contain 113 grid points, 186 elements, and have similar element number systems. Rigid body movement is eliminated by grid point constraint (accomplished by the required symmetry constraints) whereas translation normal to the disk is eliminated by constraints at the lug bolt hole positions.

A total of ten (10) computer runs were made on the two configurations. This was done to account for the different thicknesses, the concentration of the load at one point in the test, and an altered constraint to account for the bonded composite wheel.

A summary of the conditions used in the runs is shown in Table 1. This work resulted in several hundred pages of computer printout which is much too

TABLE 1. ROAD WHEEL MODELING ACCOMPLISHED BY THE USE OF NASTRAN FINITE ELEMENT SYSTEM.

RUN	MODEL	THICKNESS	WEIGHT	MATERIAL	LOAD	CONSTRAINT
1	S	0.375	20.4	al.	press.	half
3	S	0.375	20.4	al.	point	half
4	S	0.310	16.9	al.	point	half
5	C	0.500	18.9	S-Glass	press.	half
7	C	0.500	25.2	al.	press.	half
8	C	0.500	18.9	S-Glass	point	half
9	C	0.500	18.9	S-Glass	point	full
10	C	0.375	14.2	S-Glass	press.	half

extensive for detailed description. In this report the results will be discussed in terms of three (3) runs and stresses in seven (7) elements of each run.

M113 Road Wheel

Figure 3 shows the cross-section or shape of the standard aluminum M113 road wheel. This wheel has a maximum thickness of 0.375 inches (Run #1). The narrow band pressure load is shown by two vectors because only two (2) grid points fall on the outer flat portion of this configuration as it can be seen in the undeformed plot (Figure 4). A deformed grid plot is shown in Figure 5 and stress values are given in Table 2.

Composite Road Wheel

Figure 6 shows the cross section or shape of the composite wheel made of S-Glass filaments (68% by volume) embedded into an epoxy matrix. Because of the different filament angles (Figure 21), twenty (20) different material property sets were generated using computer program PLAPROP. This process was carried out for thicknesses of 0.5 inches and 0.375 inches. The load was applied at three (3) points as shown in the undeformed plot in Figure 6. Figures 7 and 8 show a undeformed and deformed plot of the grid, whereas the stress values are given in Table 2 for both thicknesses.

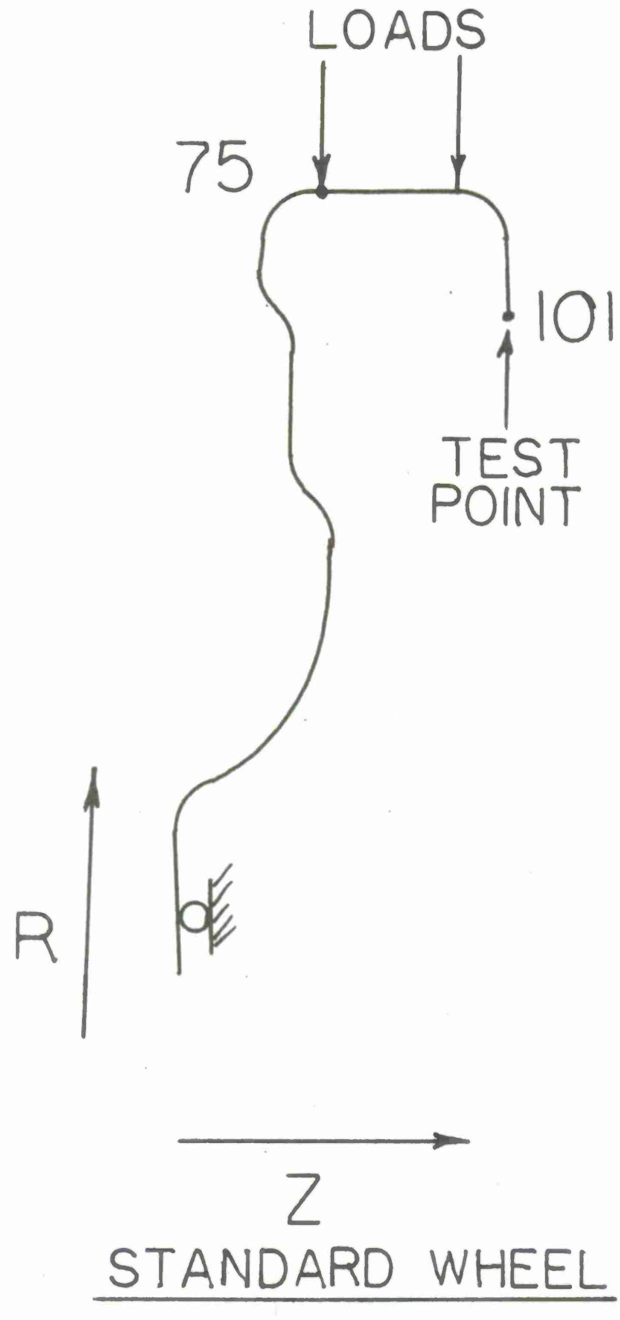

Figure 3. Schematic of M113 aluminum road wheel.

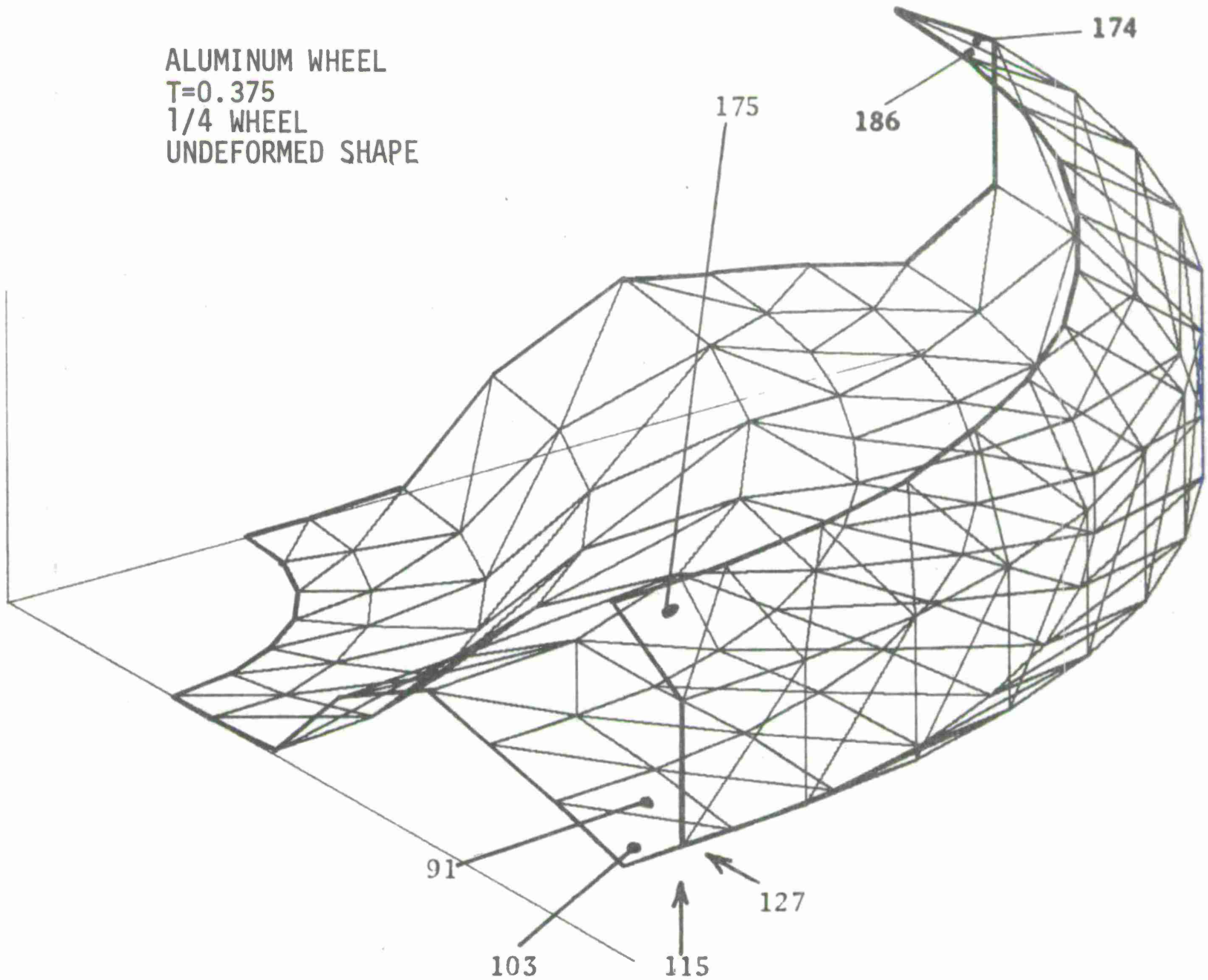

Figure 4. Undeformed shape of the M113 aluminum road wheel.

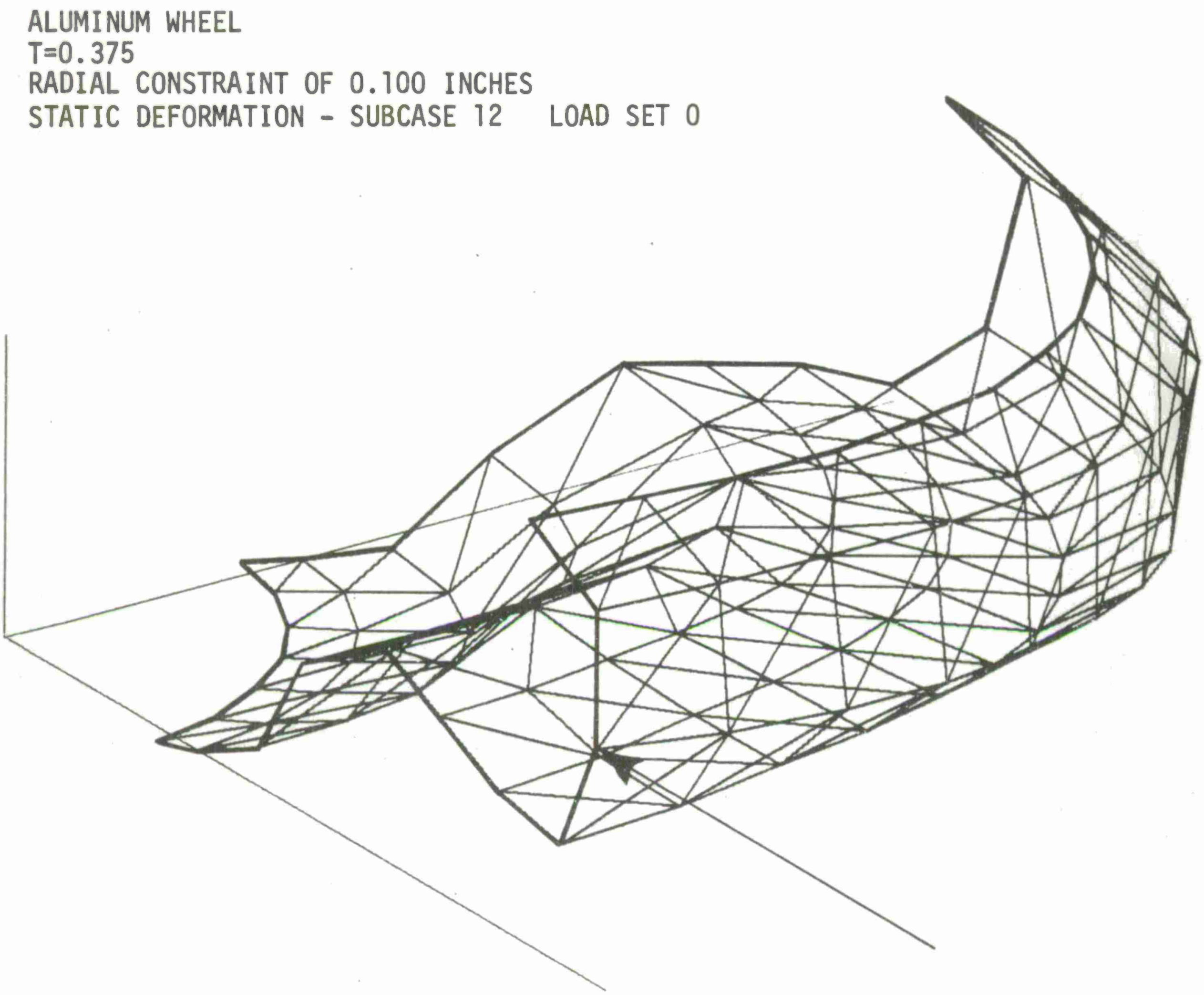

Figure 5. Deformed shape of the M113 aluminum road wheel.

TABLE 2. STRESS STATE IN M113 AND COMPOSITE ROAD WHEELS WHEN SUBJECTED TO A 12,000 POUND RADIAL LOAD.

	M113 (Run 1)		COMPOSITE WHEEL T=0.5, (Run 5)		T=0.375 (Run 10)	
Load	1.0 Pound	12,000 Pounds	1.0 Pound	12,000 Pounds	1.0 Pound	12,000 Pounds
Max. stress						
91	-4.76	-51,100	-0.57	-6,800	-0.59	7,080
103	-6.12	-73,400	-1.59	-19,100	-2.14	25,700
115	-4.32	-51,800	-0.89	-10,700	-1.32	15,800
127	-5.36	-64,300	-1.96	-23,500	-3.10	37,200
174	-1.04	-12,500	-0.72	-8,600	-0.99	11,900
175	7.03	84,400	0.85	10,200	1.18	14,200
186	-2.83	-34,000	-1.23	-1,480	-1.66	19,900
Max. shear stress						
91	1.17	14,000	0.11	1,300	0.10	1,200
103	1.86	22,300	0.53	6,400	0.76	9,100
115	1.72	20,600	0.23	2,800	0.37	4,400
127	1.85	22,200	0.59	7,100	1.12	13,400
174	0.74	8,900	0.34	4,100	0.47	5,600
175	4.28	51,400	0.67	8,000	0.98	11,800
186	1.31	15,700	0.58	7,000	0.79	9,500

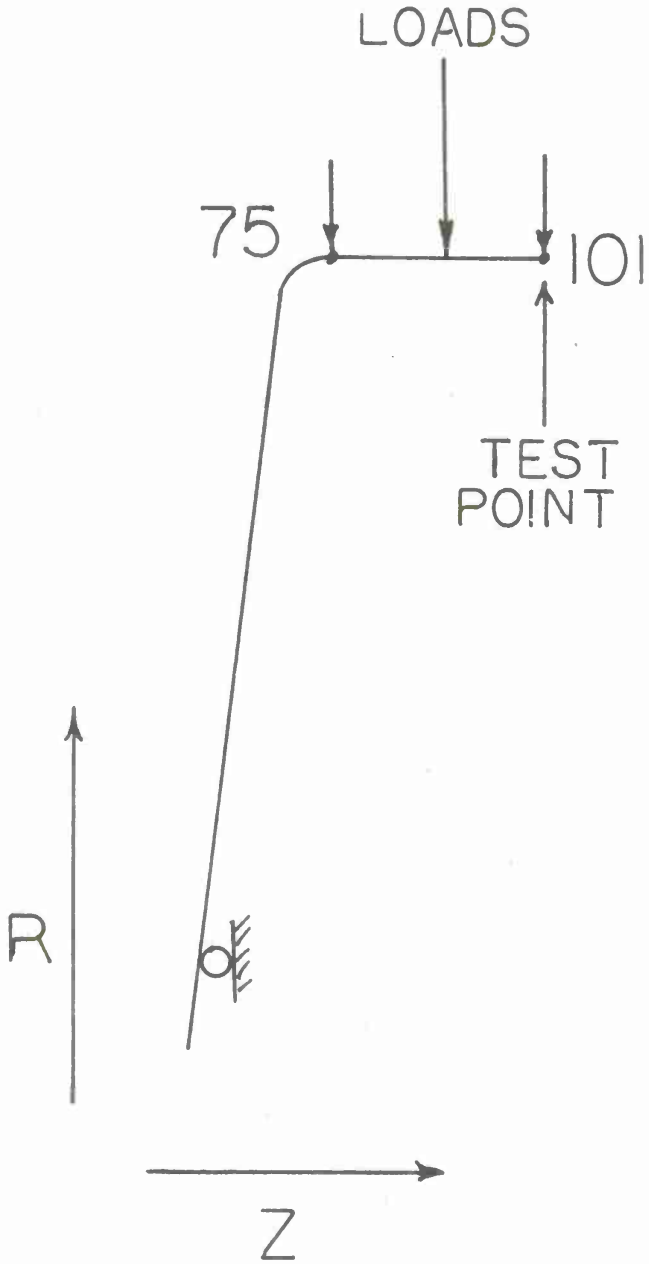

Figure 6. Schematic of the composite road wheel.

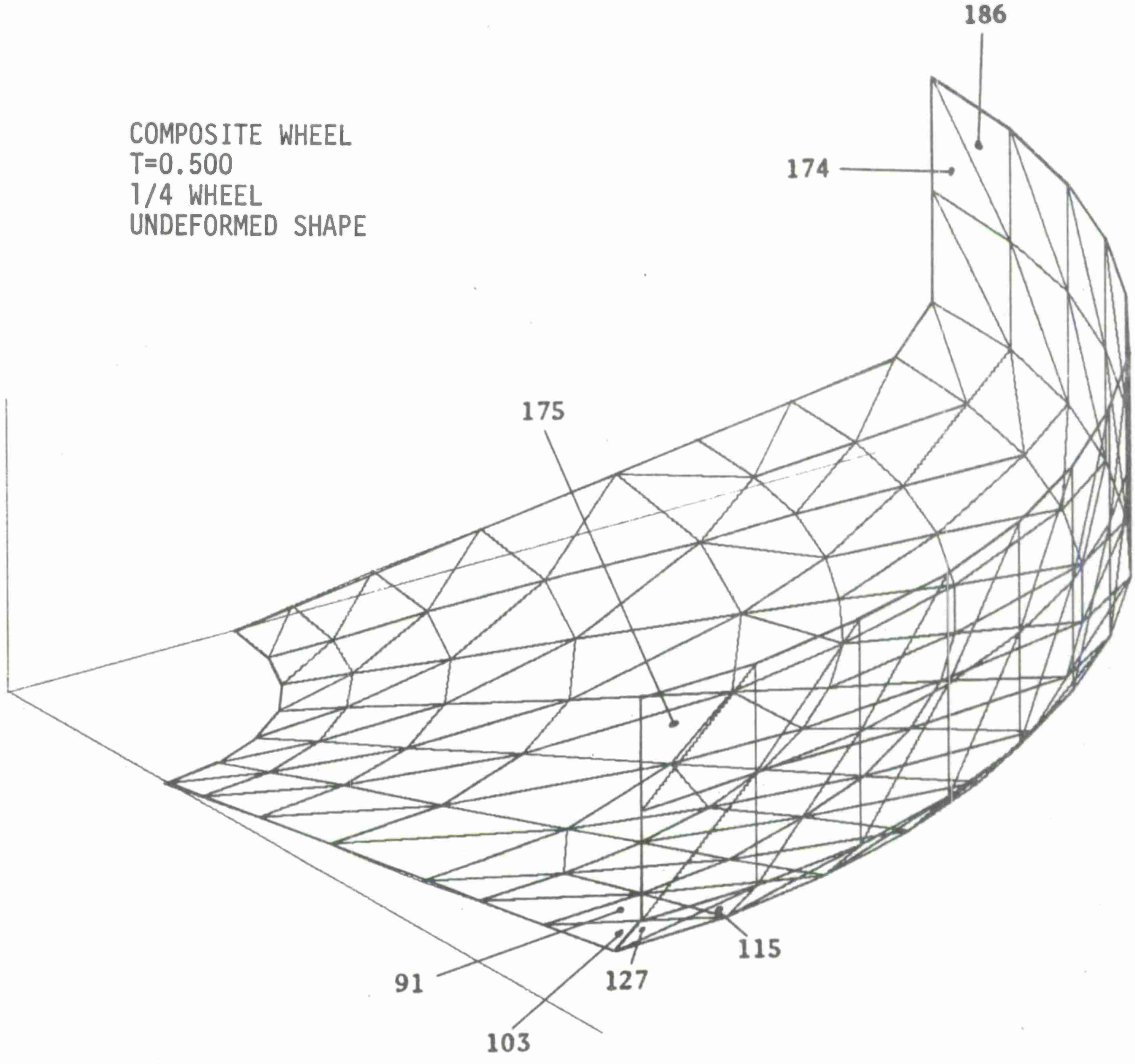

Figure 7. Undeformed shape of the composite road wheel.

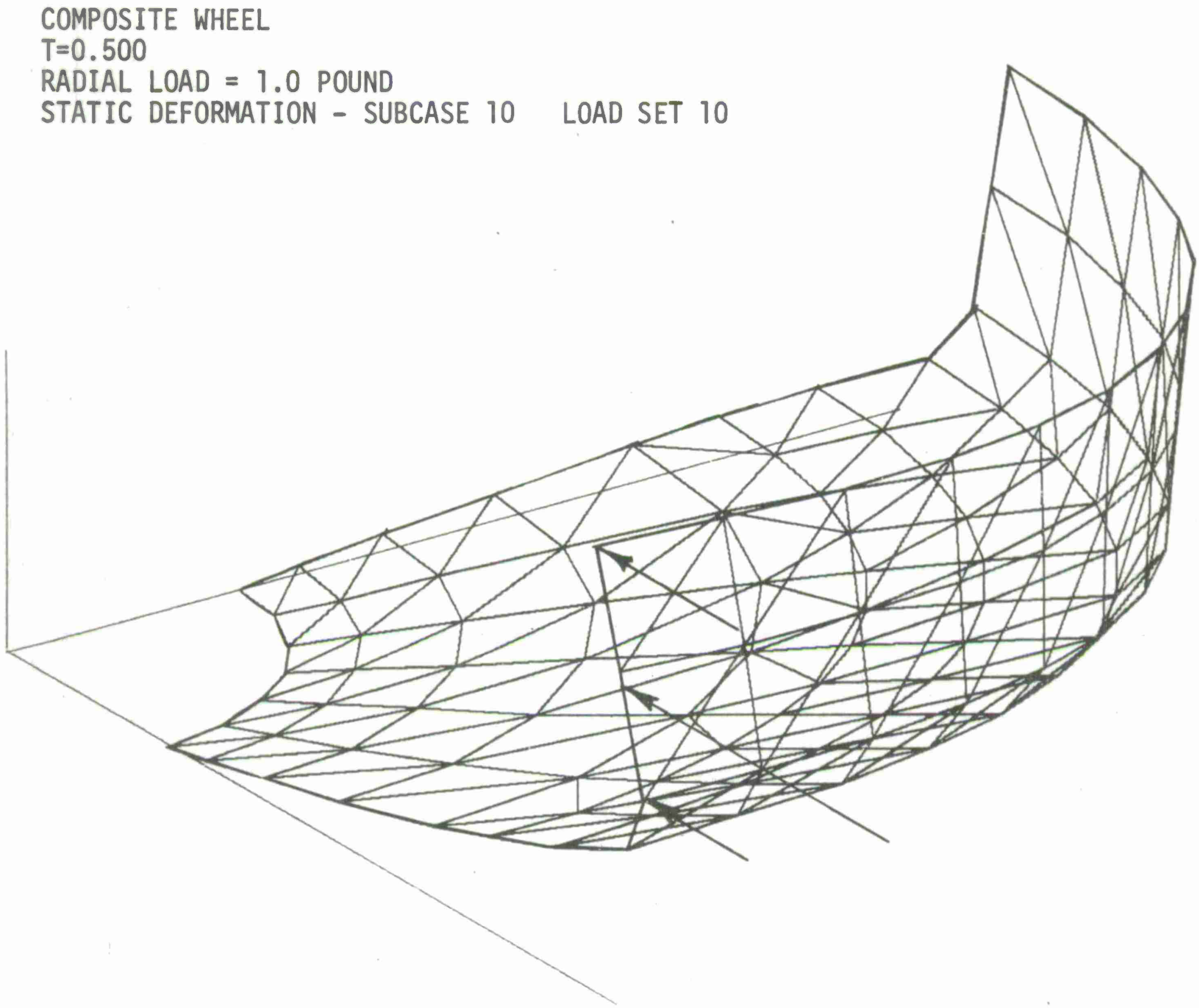

Figure 8. Deformed shape of the composite road wheel.

II. FABRICATION

The composite road wheel was fabricated by using a sophisticated filament winding machine (Figs 9 and 10). This versatile machine is an electronically-controlled, programmable, servo-driven unit with a high degree of winding flexibility. This machine will helically wind all stable shapes from 1 to 90°, polar, and hoop. Cones and objects with unequal pole diameters and varying winding angles are all within the capabilities of this machine. Once the interface drawing is made available, a mandrel and a machine program (obtained by the computer program GEOD) are then used to wind the composite structure. Figures 11 and 12 depict the traversing mechanism loaded with spools of glass, and Figure 13, a close-up view of a constant tension device (the tension of the glass roving, throughout the manufacturing process, was maintained at 6 lbs/roving). Figures 14 and 15 depict the photo control system without and with the drum supporting the plotted winding pattern obtained from Computer Program "GEOD". Details on the machine can be found in the Watervliet Arsenal Instruction and Maintenance Manual on the Filament Winding Machine Model 830-140, serial number 1088. Figure 16 depicts a M113 conventional disk and the mandrel designed for the composite wheel. The present filament delivery mechanism had to be redesigned to accomodate the low angle of wrap needed to wind mandrel of Figure 16; see pulleys arrangement shown in Figure 17. After mandrel is wrapped, the whole structure is cured under controlled conditions, later the composite component is released from the mandrel and the two disks obtained are located back to back on a second mandrel and re-set in the filament winding machine

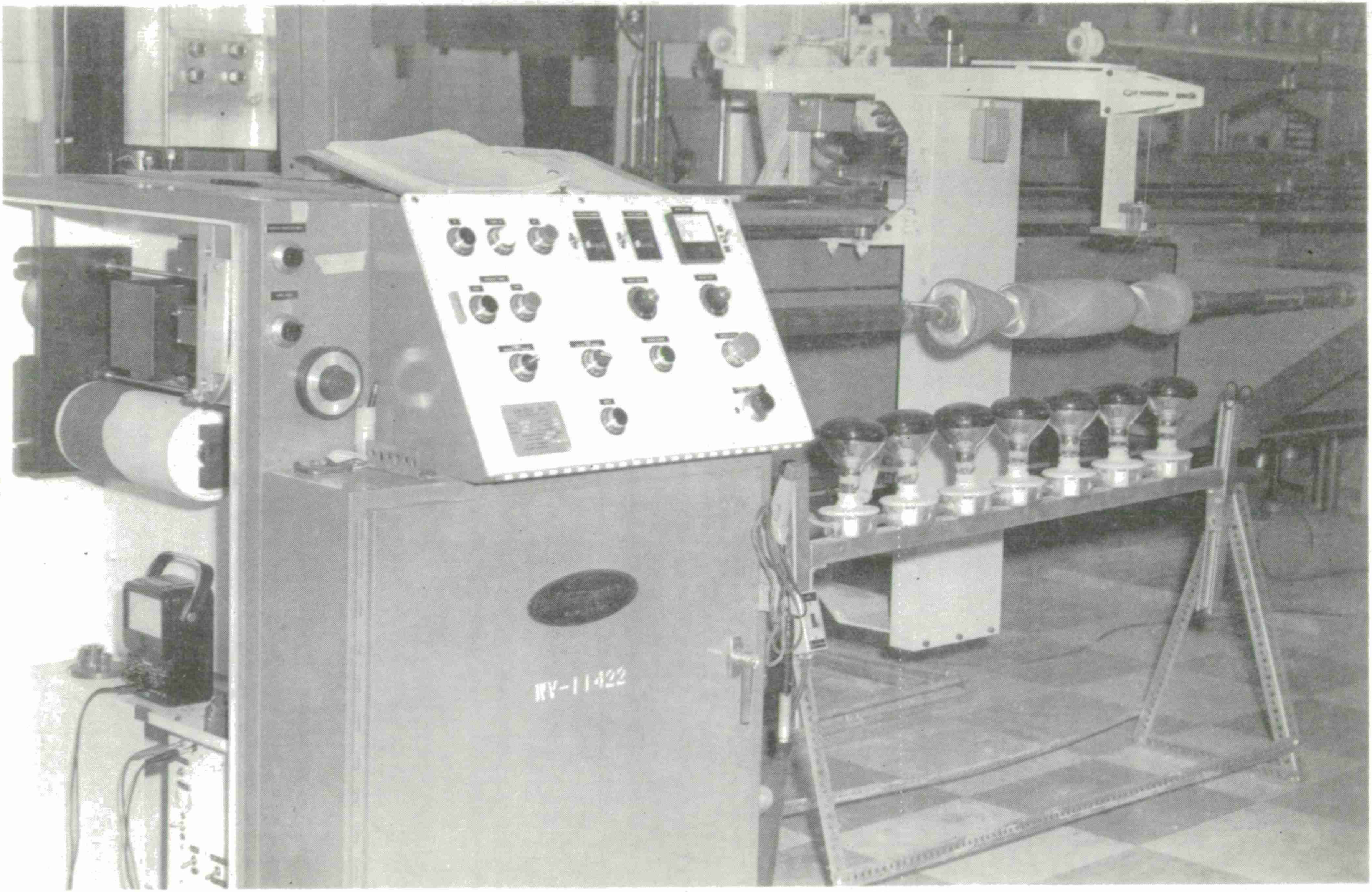

Figure 9. Overall view of the photo controlled, servo driven, filament winding machine.

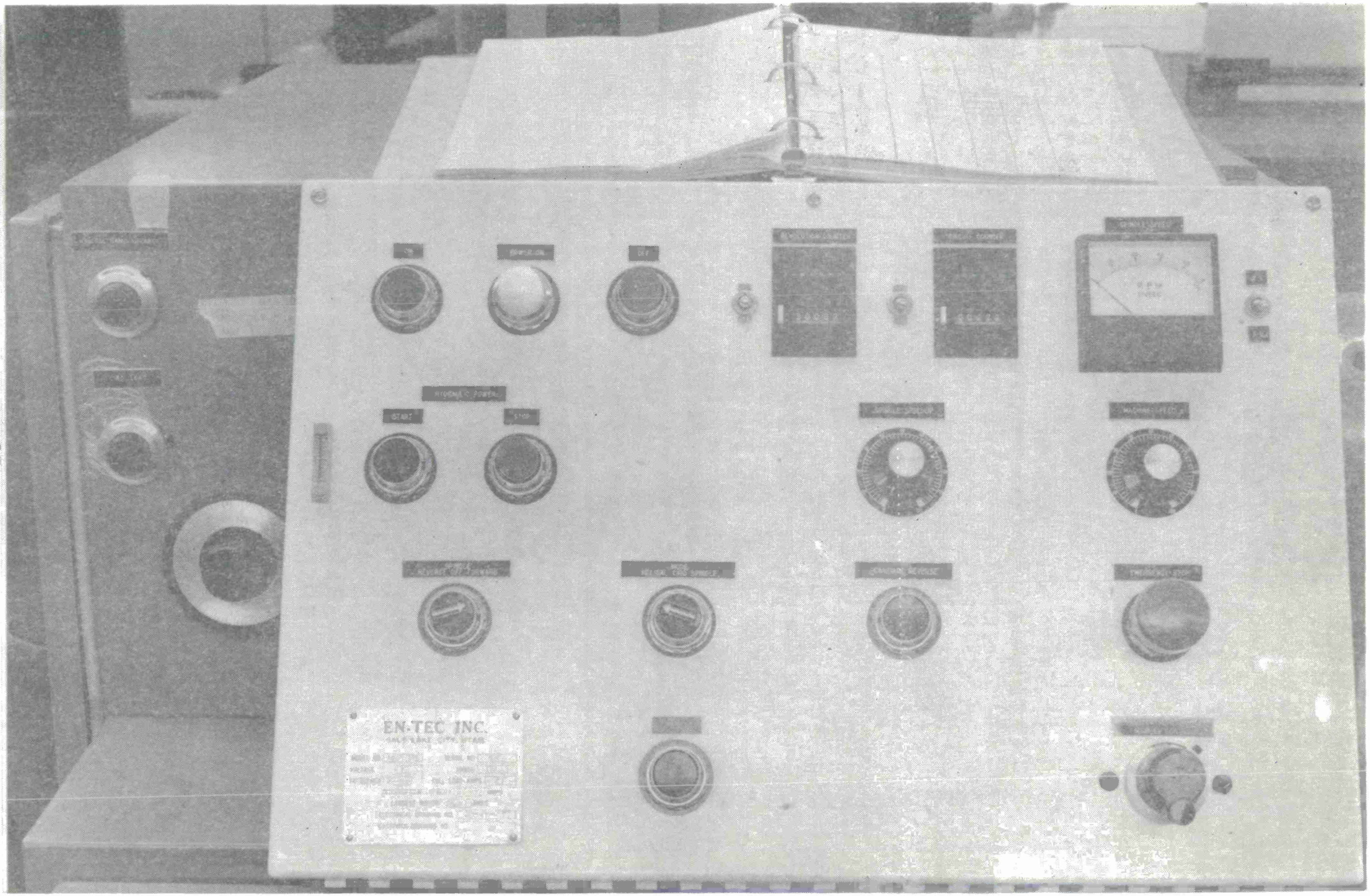

Figure 10. Close-up of control panel of winder.

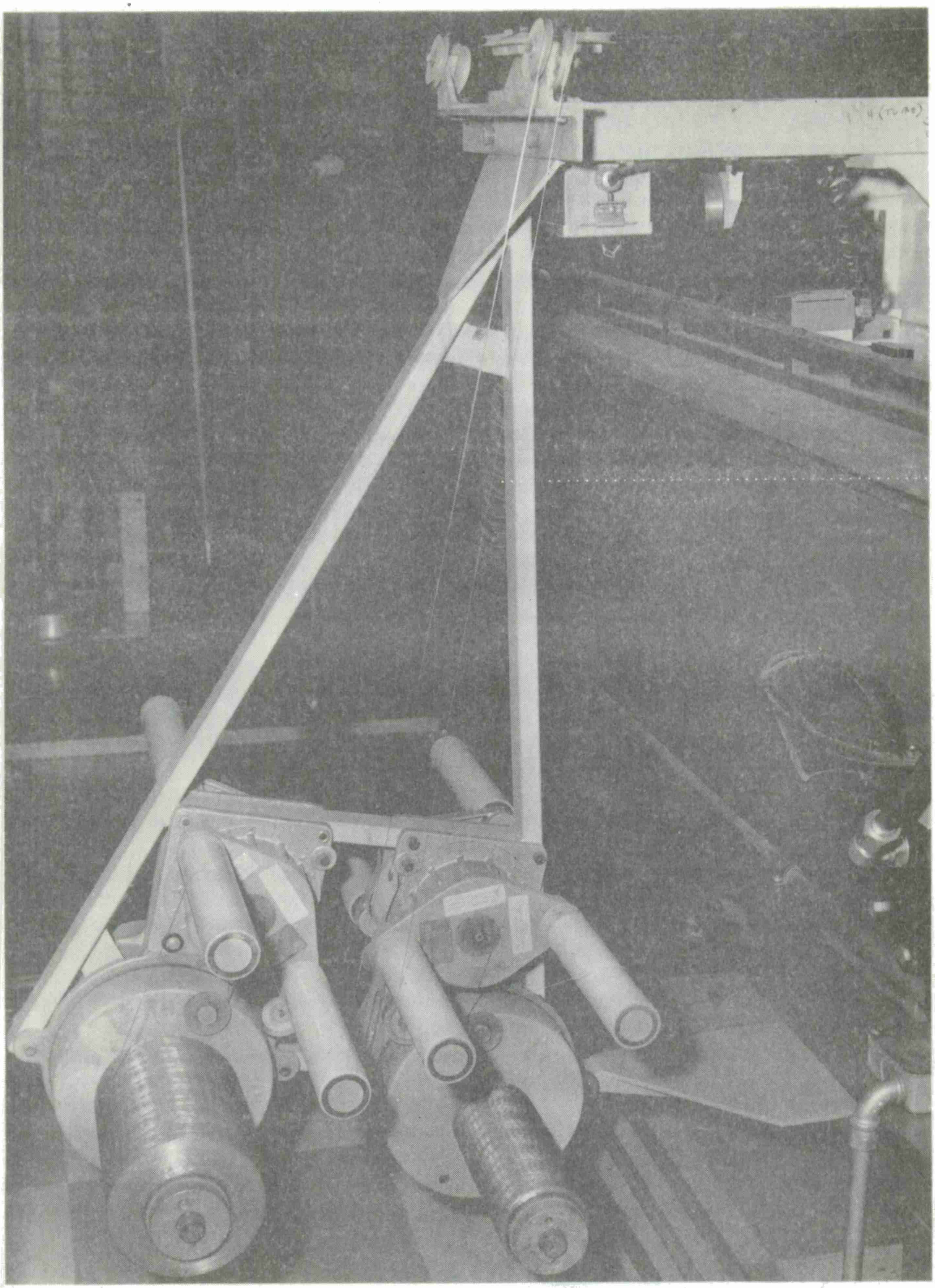

Figure 11. Side view of traversing mechanism.

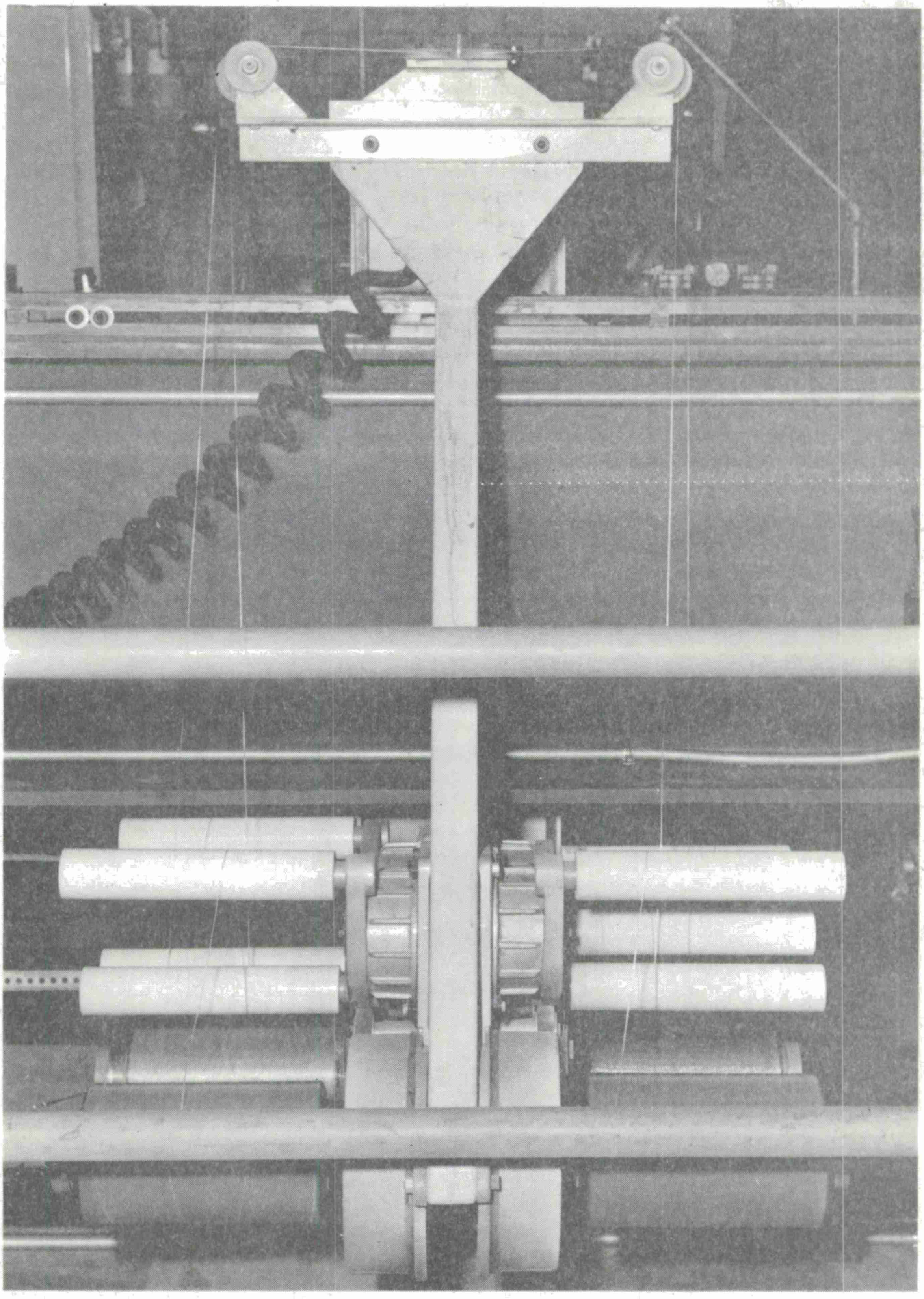

Figure 12. Rear view of traversing mechanism with four tension devices (with spools).

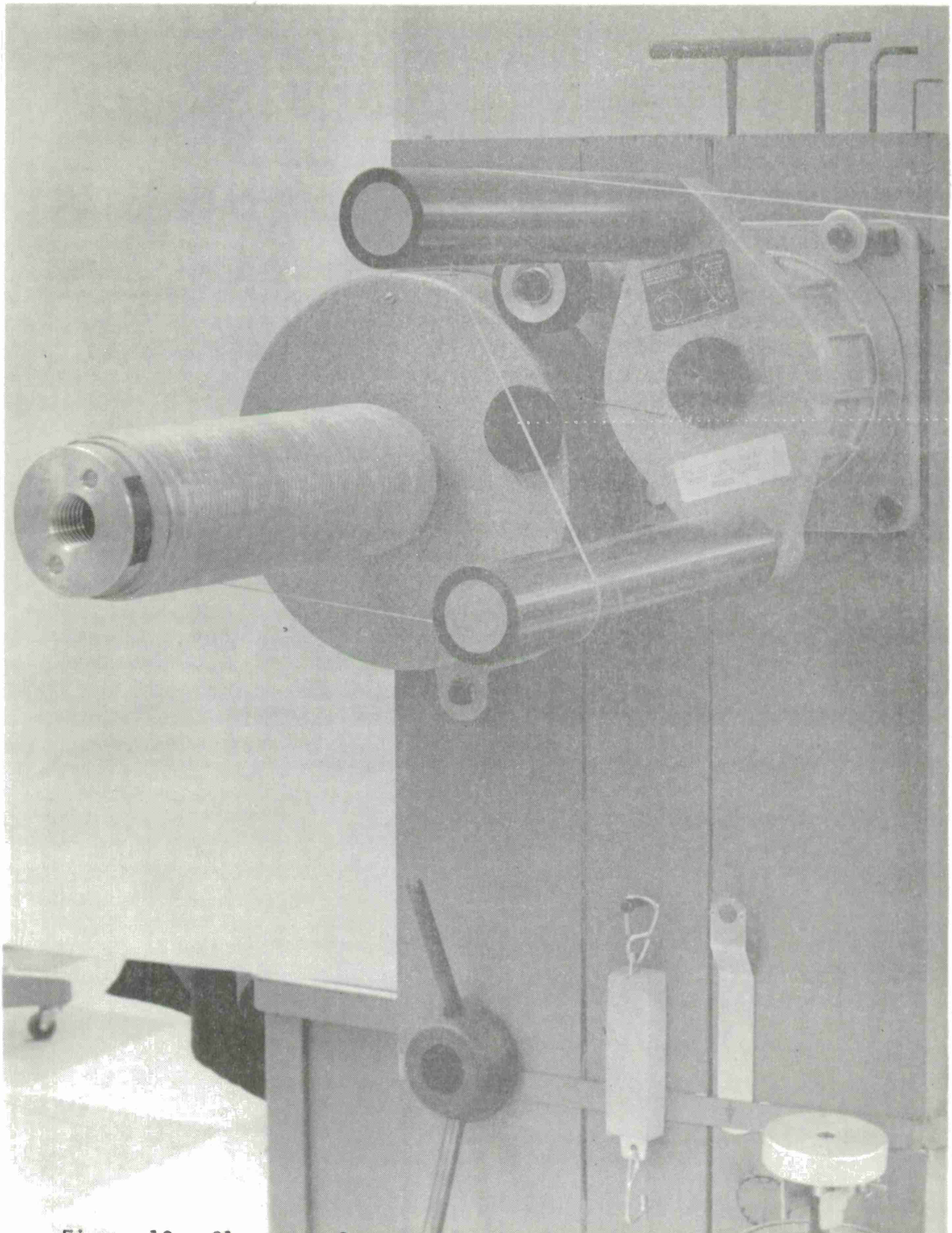

Figure 13. Close-up of a compensating type tensioning device used for the pre-preg glass roving.

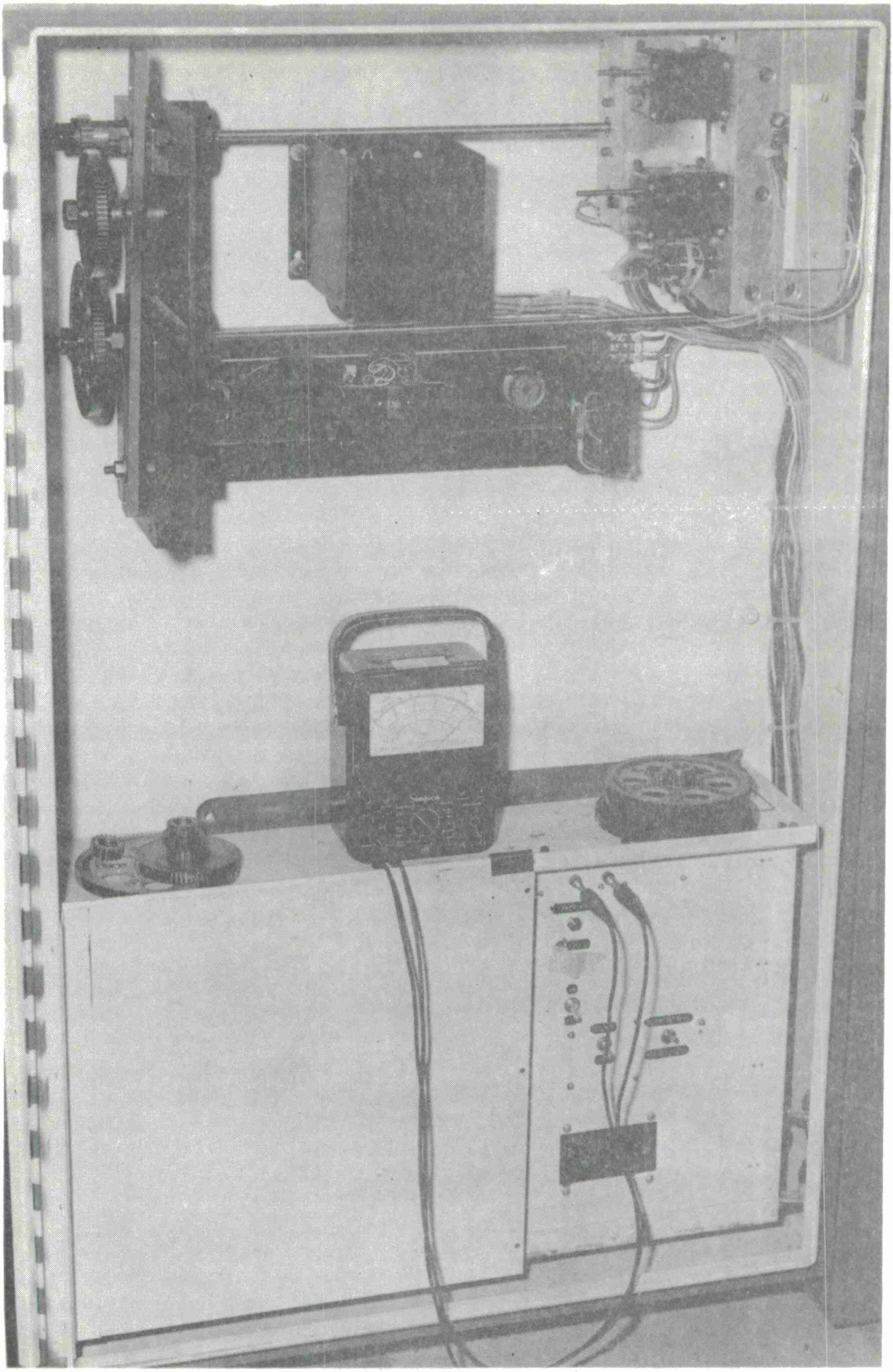

Figure 14. Close-up of winder's photo control mechanism.

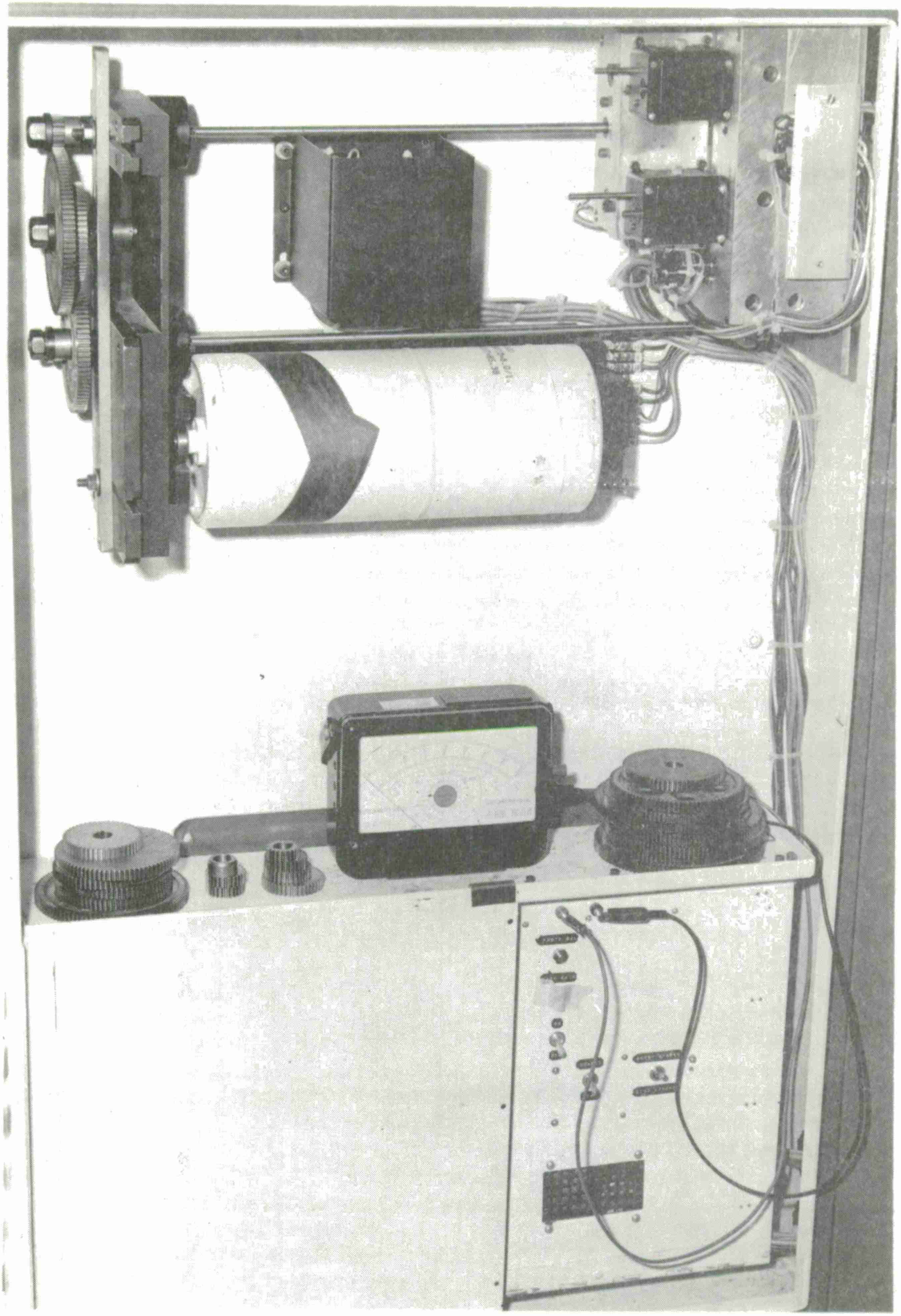

Figure 15. Photo control mechanism with program on drum.

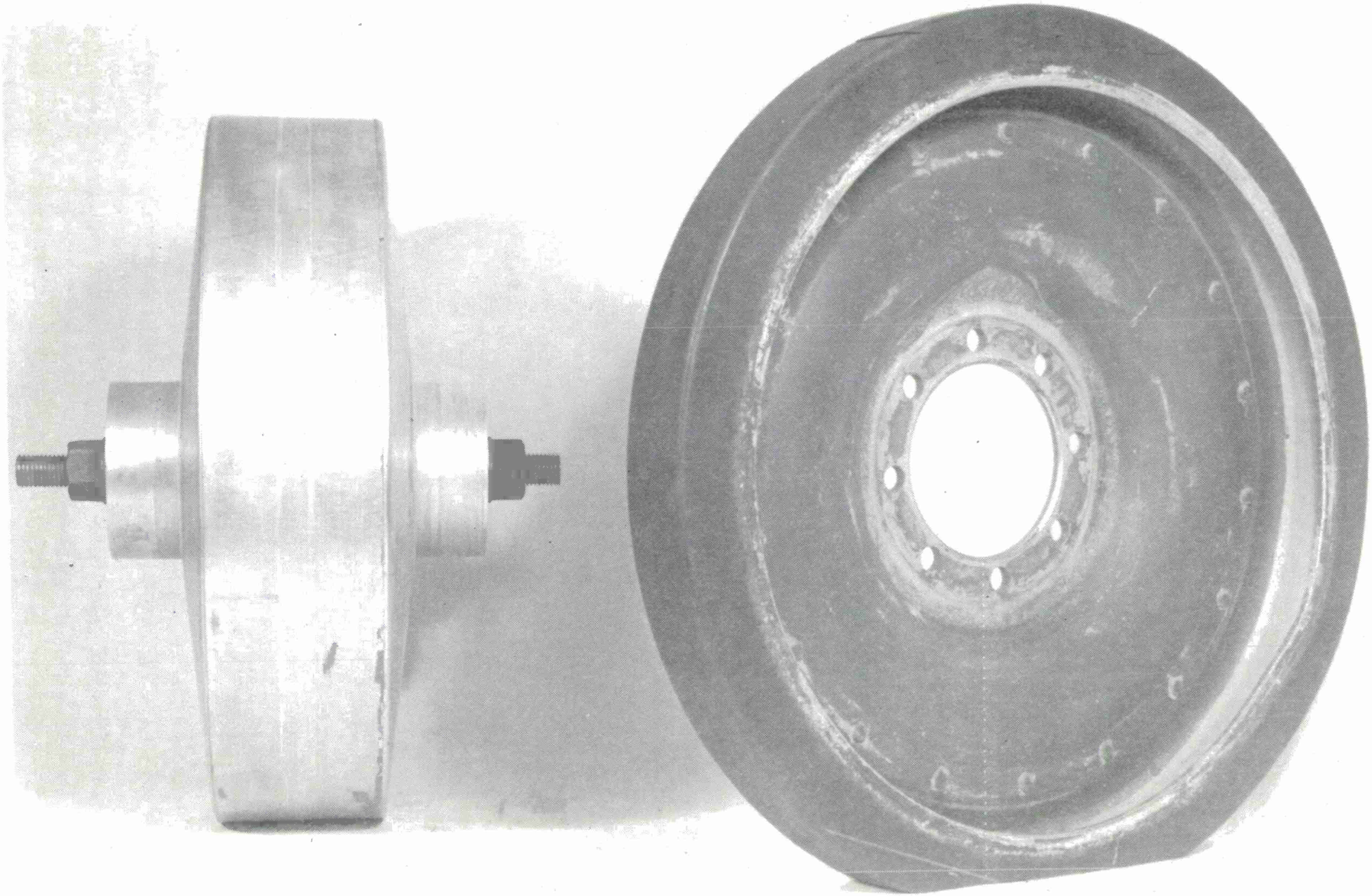

Figure 16. Composite road wheel mandrel and M113 disk.

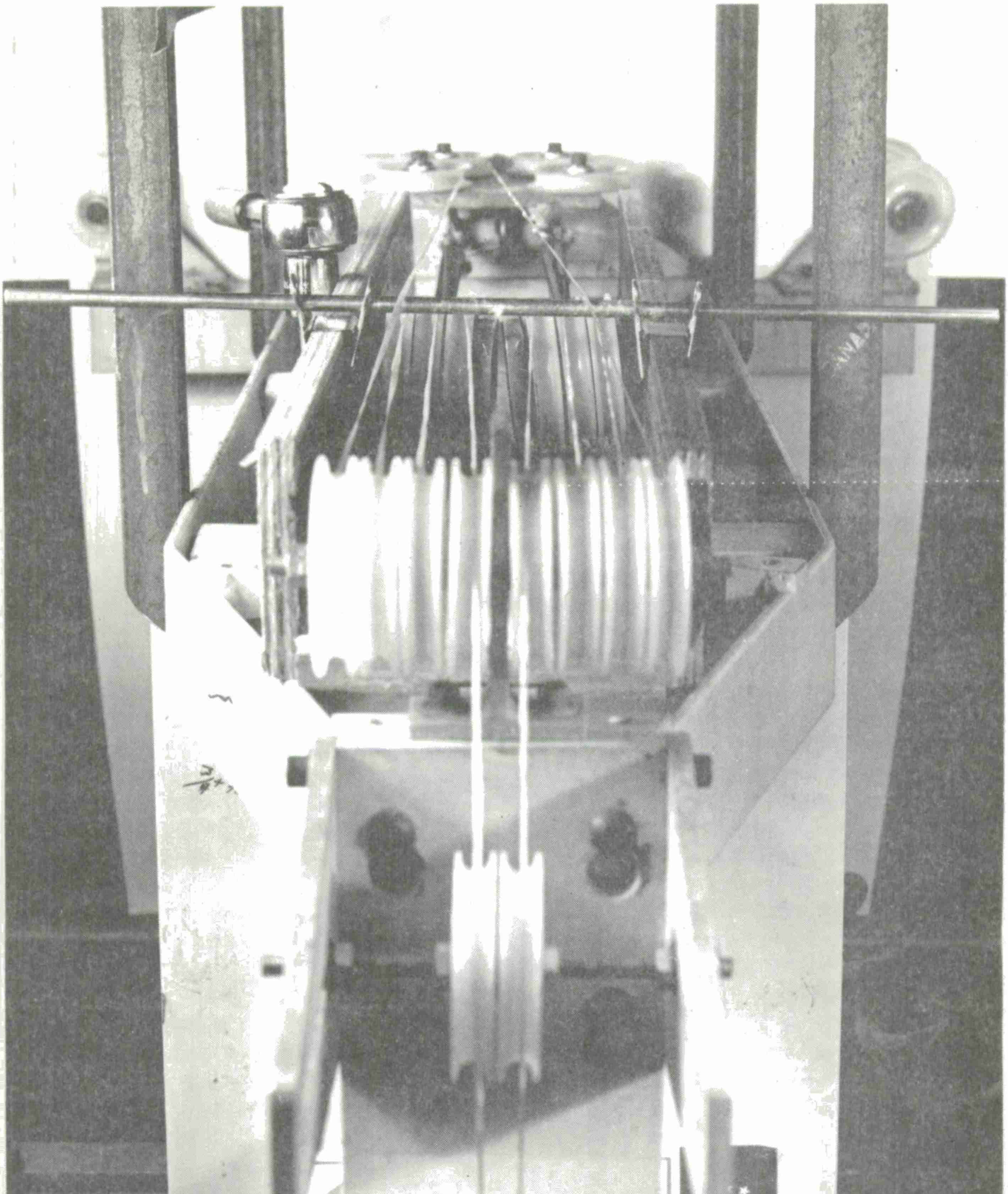

Figure 17. Pulley arrangement to wind mandrel shown in Figure 14.

as shown in Figures 18 and 19. Figure 20 shows the last wrapping or filament winding operation which provides the proper gap or clearance for the track indexing lug. Eight filament winding programs were used to complete the composite road wheel. A typical filament winding program as obtained from the computer is displayed in Figure 21; this program was used to wrap the mandrel shown in Figure 16.

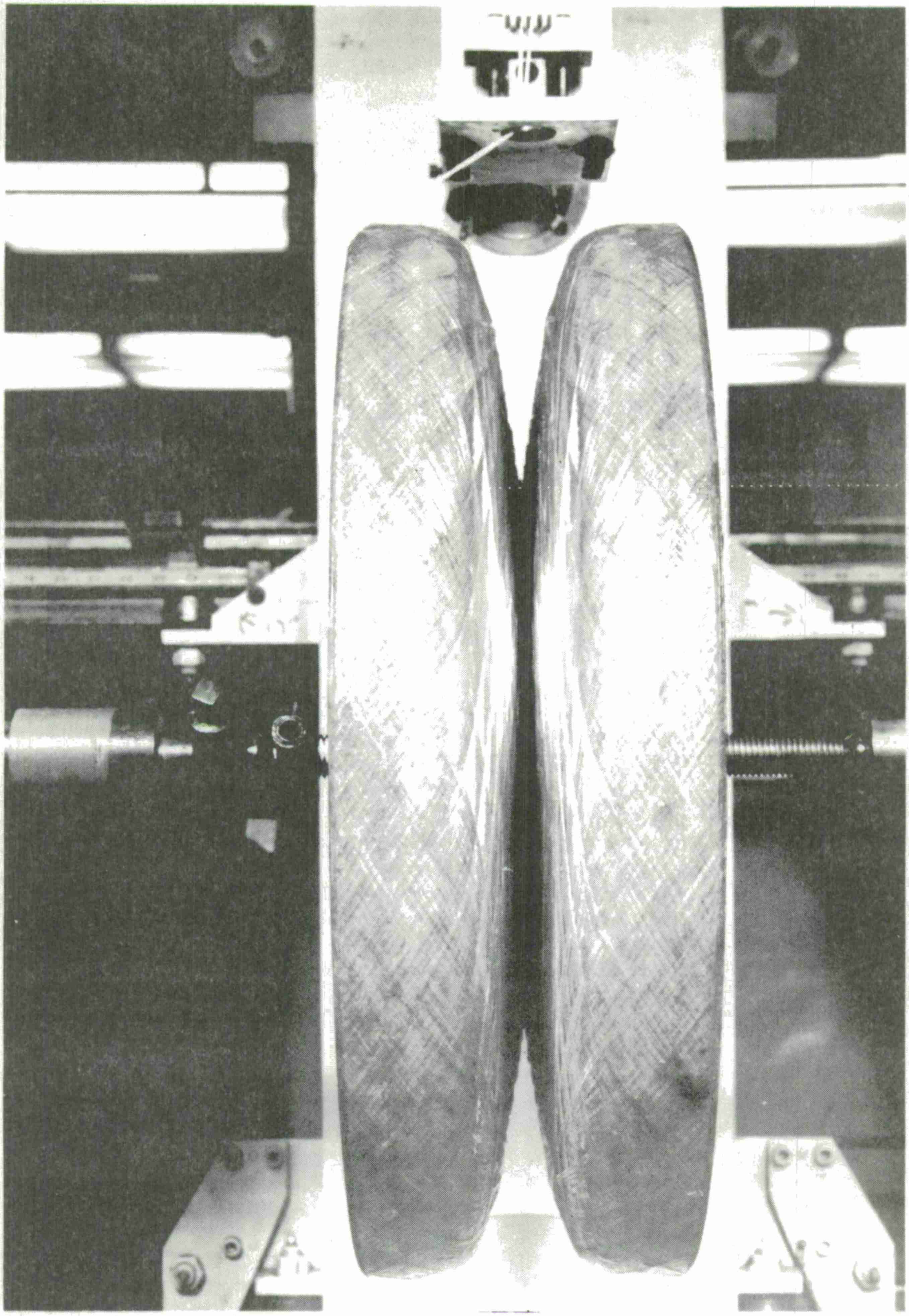

Figure 18. Composite road wheel disks after separation from mandrel and placed back to back for further winding.

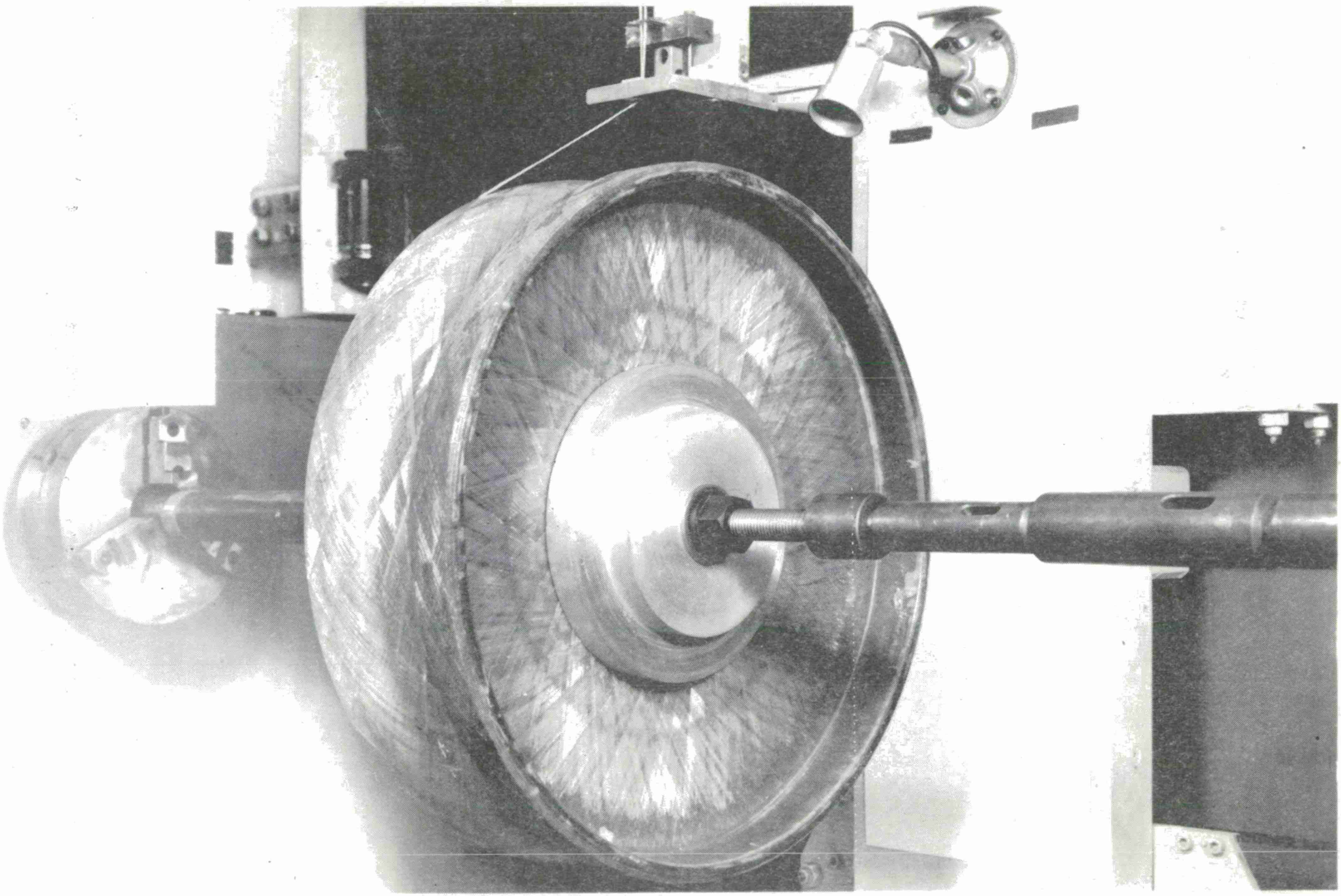

Figure 19. Side view of road wheel.

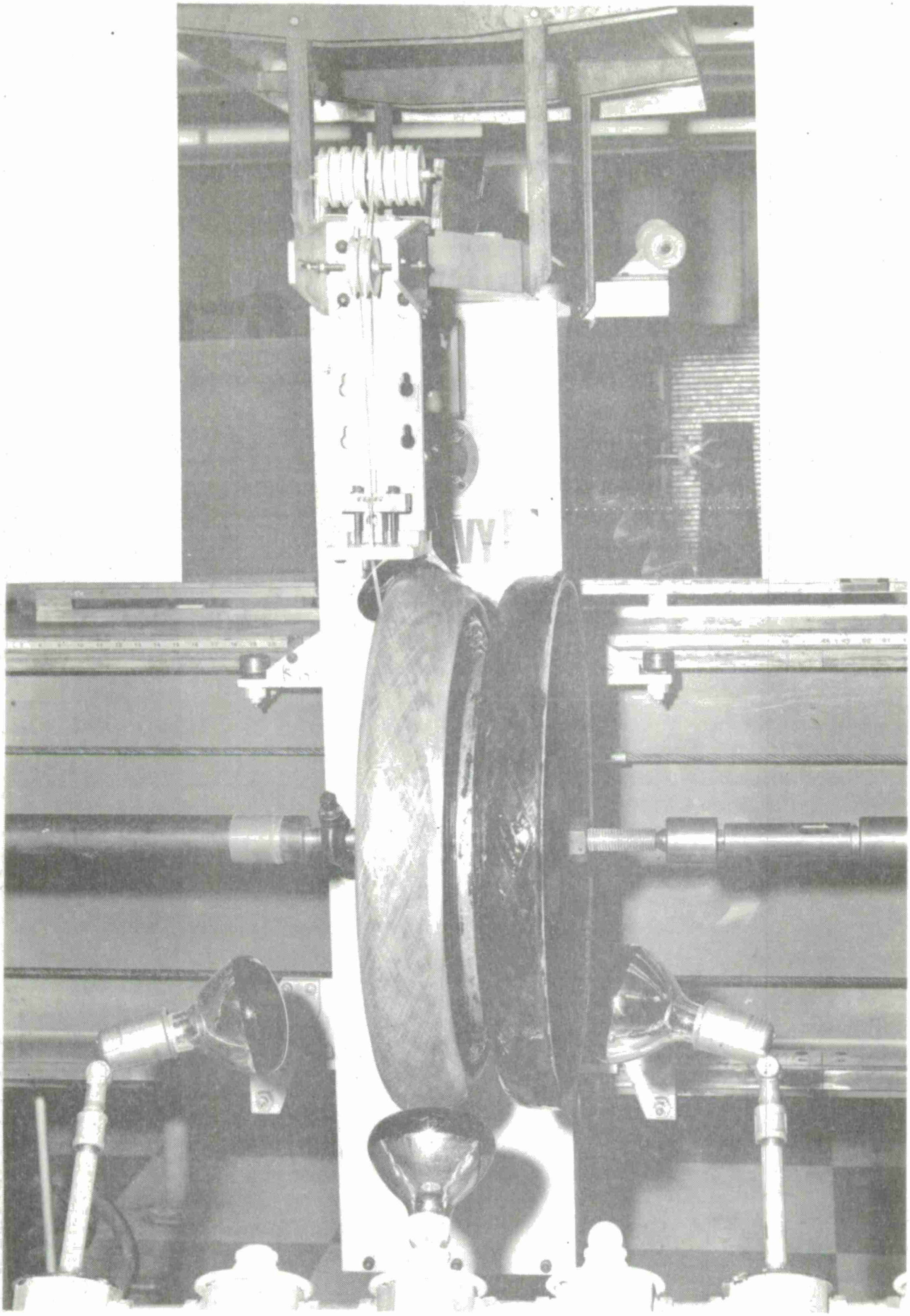

Figure 20. Composite disks wound to provide clearance for track indexing lug.

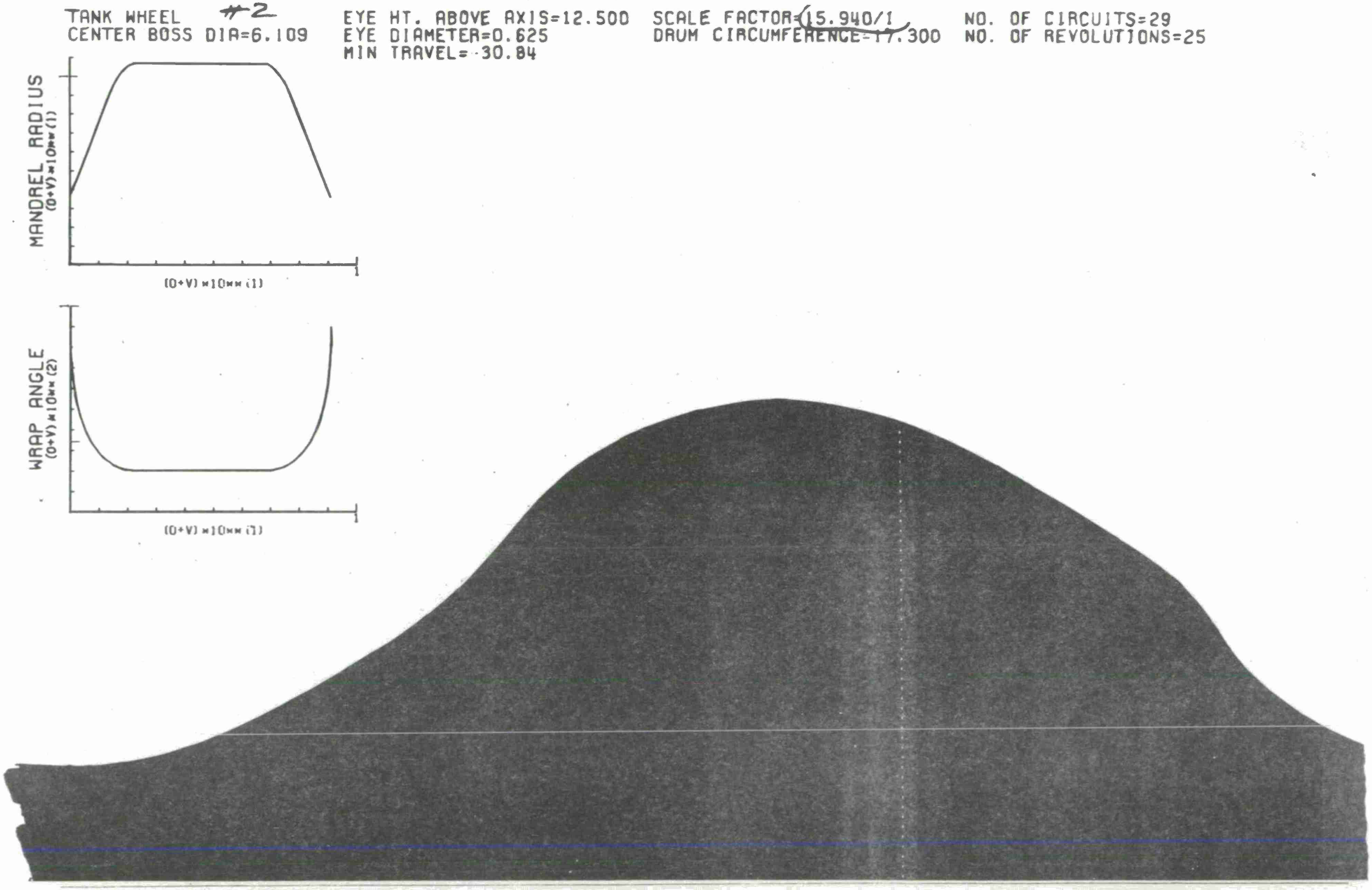

Figure 21. Typical filament winding program showing also mandrel geometry and angle of wrap vs distance.

III. TESTING

Three tests were performed in a Baldwin-Tate-Emery 120,000 pound Universal Testing Machine. In each dial indicators were used to measure compliance across the diameter of the test point shown in Figures 3 and 6. In each case the maximum load used was set primarily to give a substantial reading on the dial indicators.

The three tests were:

a. Large disk of the M113 road wheel.

b. Large disk of the composite road wheel.

c. The finished composite road wheel.

The plots of the data are shown in Figures 22, 23 and 24; a summary of the compliances are given in Table 3.

This program has presented great difficulties in the comparison of the test and theoretical results, hence several computer programs were required to find a suitable loading condition to simulate the test. Runs 3 and 4 were the results of uncertainty about the thickness of the 113 wheel: thus the theoretical data is given in terms of an upper and lower bound on thickness.

In the case of the single disk of the composite wheel there is a rather large difference between the material properties used in the analysis and the finished disk; this produces a rather large error.

The test on the finished wheel presented another problem since one disk was about 0.05 inches smaller than the other and steel shims were used to improve the contact condition between the wheel and the table of

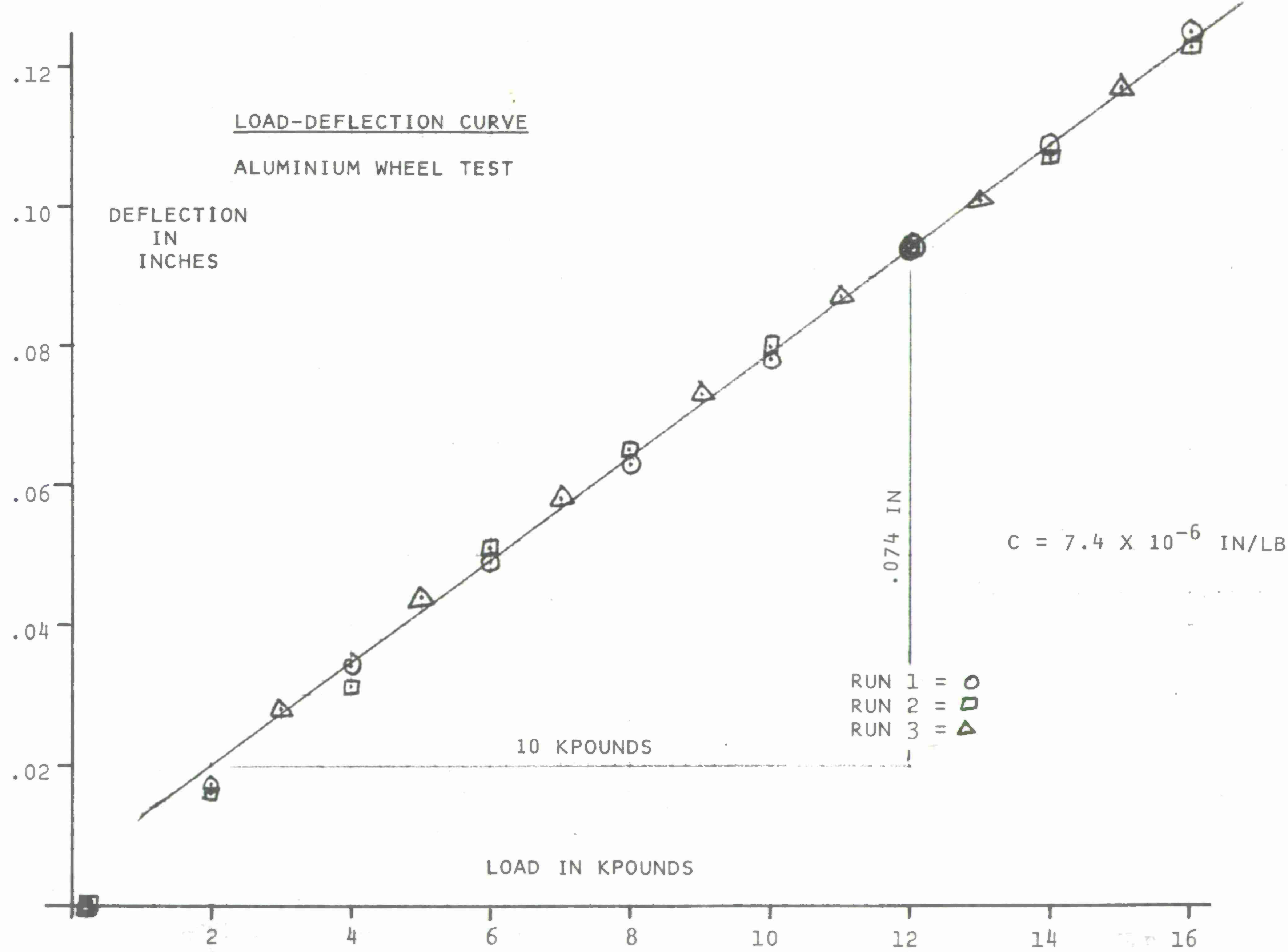

Figure 22. Load deflection curve for the M113 aluminum disk (without rubber pad).

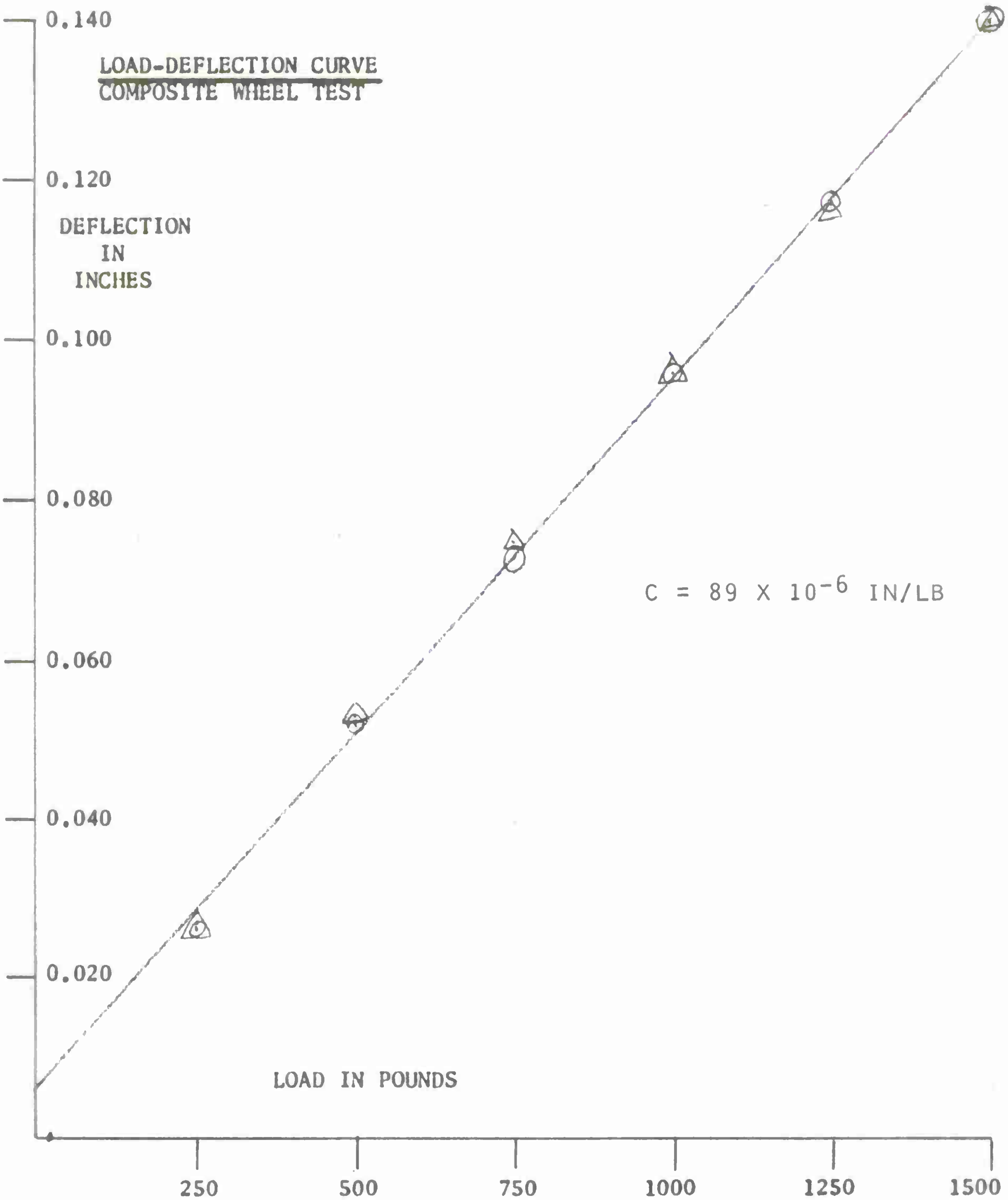

Figure 23. Load deflection curve of one composite disk.

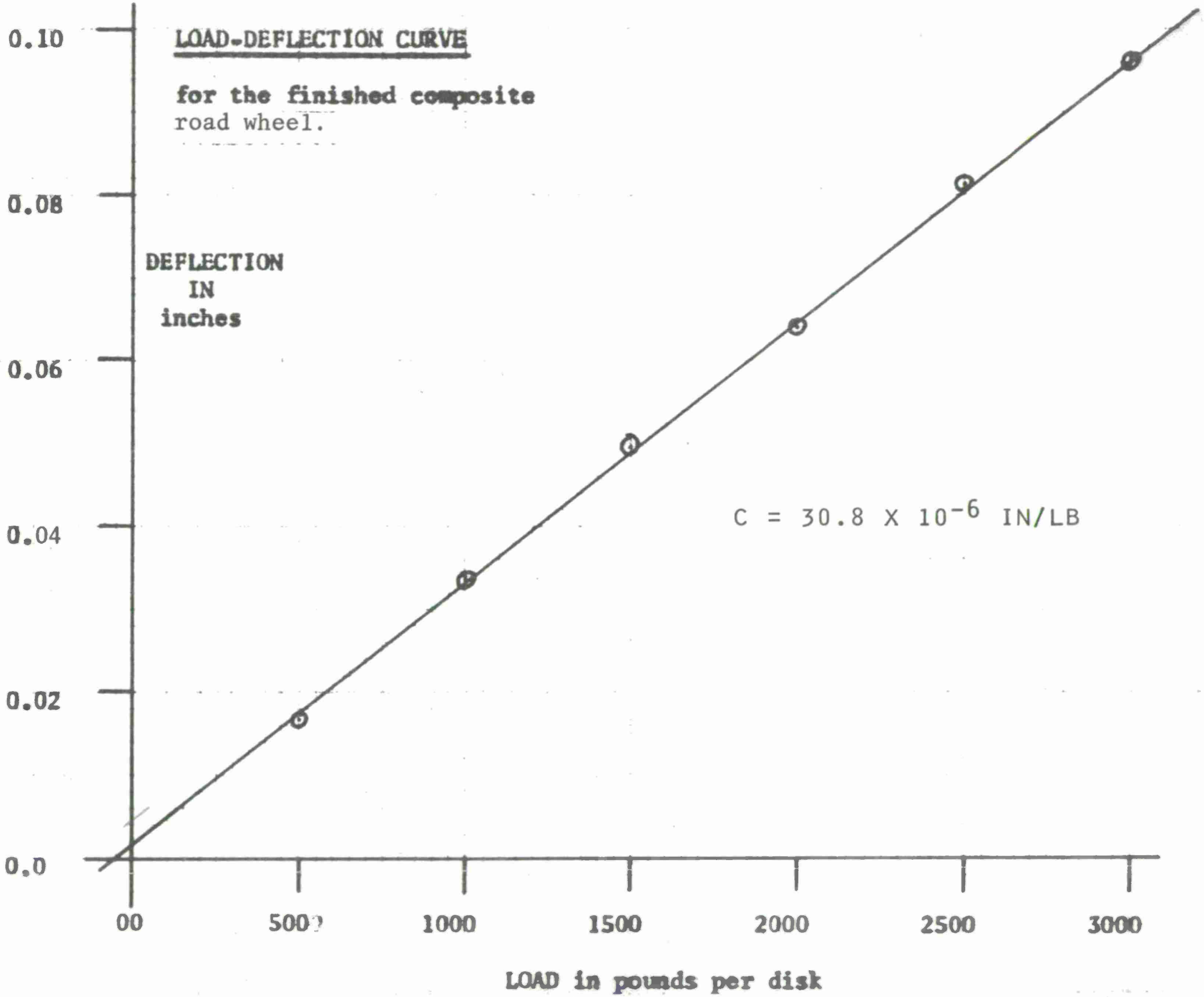

Figure 24. Load deflection curve of the prototype composite road wheel.

TABLE 3. COMPLIANCE* DATA FOR THE TEST AND THEORY

TEST		THEORY		
M113 Single Disk	7.4	UPPER BOUND	5.54	(Run 3)
		LOWER BOUND	8.27	(Run 4)
Composite Single Disk	89.0		19.9	(Run 8)
Composite Finished Wheel	30.8		22.8	(Run 9)

* Compliance in micro inches per pound load

the machine. In both of the composite wheel tests thin pads of rubber were used between the steel of the machine and wheel. In this case the rubber prevents lateral expansion of the wheel which in turn decreases the apparent compliance.

IV. CONCLUSIONS AND RECOMMENDATIONS

The feasibility of fabricating a M113 road wheel by the filament winding process has been demonstrated.

It can be seen in Table 2 that the stresses in either composite wheel configuration are generally lower than the M113 wheel, however, these values must be compared with a failure criterion for the material.

If the Tresca yielding criteria were applied to the M113 wheel and the tensile strength of the aluminum is 70,000 psi, yield would start at a maximum shearing stress of 35,000 psi. This stress is exceeded only in one element (#175) in Table 2, and a small plastic region at the 12,000 pounds load does not seem to be a serious problem.

The maximum shear failure is a controlling factor in composites. Shearing strength of composites are function of methods of fabrication. For example in the filament winding operation, because of filaments "cross-over" shearing strengths up to 35 Ksi have been reported for Glass/Epoxy systems; whereas in compression molding operations maximum shearing strength reported has been around 13 Ksi.

If 13,000 psi shearing strength is used for the composite wheel, this stress is exceeded only in one element (#127) of the thinner (.375") wheel.

The thinner wheel (the 0.375" thick) was introduced when the 0.5" thick wheel produced very low stresses. This configuration produces a 30% reduction in weight if weights in Table 1 are used (Note: Aluminum wheel weight of Table 1 excludes steel wear ring).

It is unfortunate that neither of these cases is a good model for the wheel which was fabricated. The theoretical model used material property definition parameters based on Figure 6, whereas the first and only composite road wheel shown in Figures 1 and 2 was fabricated mainly to show the feasibility of the filament winding process.

The rims are thicker than had been anticipated since the filament winding operation included a series of hoop windings which are now found to be unnecessary. The elimination of these windings will reduce the prototype wheel weight by approximately 5 lb. The prototype composite road wheel as shown in Figures 1 and 2 weighs 46.5 lb, while the M113 aluminum road wheel (which includes rubber) weighs 68 lb.

It is felt that the constraints that were imposed by trying to adapt filamentary composite materials to an already existing structure could detract from fully demonstrating the value of composites. Although low weight saving was achieved with the first prototype, there is a significant potential for further improvement of design, and fabrication is uninhibited by the present instilled metals technology.

An example is found in the DARCOM 6.1 Assessment Meeting of 6 Feb 76. In Assessment Report A#51 - Combat Support - MERDC page 27 there is a mention of using composites for tracked vehicle wheels. When MERDC was contacted, it was learned that

a. MERDC's main interest is in improved blast survivability of vehicle components designed in combination of metals and glass-epoxy composites.

b. An experimental tank road wheel made from high strength composite material, retained an acceptable degree of serviceability when subjected to a blast of 25 lb of high explosives.

c. The aforementioned road wheel made by a private contractor did not have constraints as far as wheel geometry, weight, and cost, since the wheel is a component of an experimental concept. This last finding was very important since it shows an awareness that the structural and fabrication concepts which must exploit the unique characteristics of composites (weight reduction; high strength) have to be implemented in the initial stages of the total system configuration development. On the other hand, if composite materials are used to exploit and/or optimize an existing metal component (such as it has been in this project) then the buyer has to be aware of limitations encountered on weight, production, and cost.

It is recommended:

a. To continue work on present concept per plan outlined in "Introduction".

b. From a fabrication point of view, it is felt that a more economical way to build the present composite road wheel would be to mate a compression molded process with the filament winding process. The molding process will be used to make a wheel mandrel, while the filament winding process will be used to reinforce this mandrel for the desired load capacity.

c. If vulnerability is of interest it is felt that filament winding is the process to use in obtaining an economical structure. Figure 25 depicts a composite road wheel made of axisymmetric structures, weighing approximately 120 lb, while Figure 26 depicts a second concept weighing approximately 100 lb. To prove blast survivability, tests have to be performed for either concept.

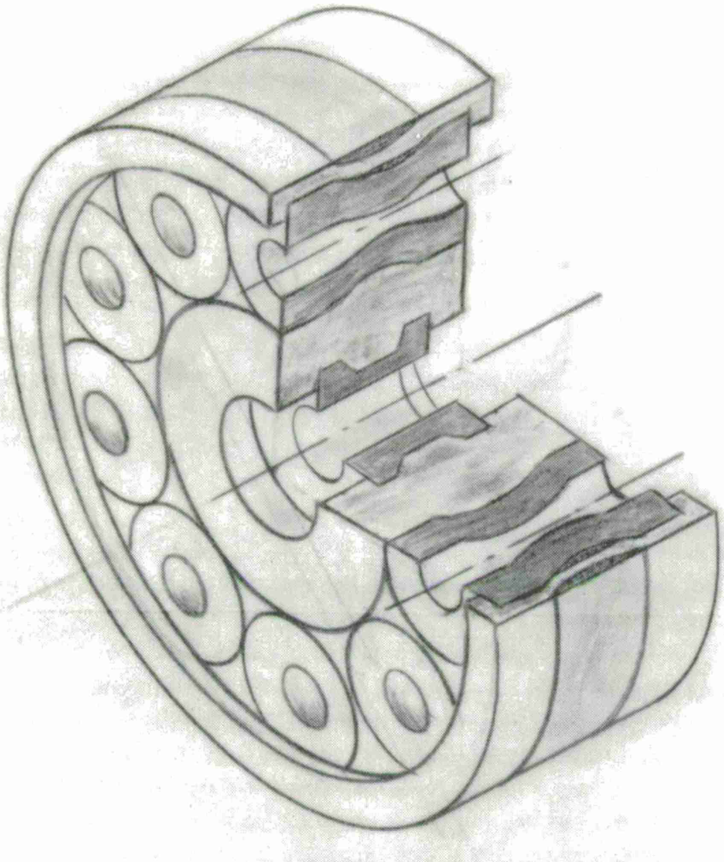

Figure 25. Composite road wheel #1.

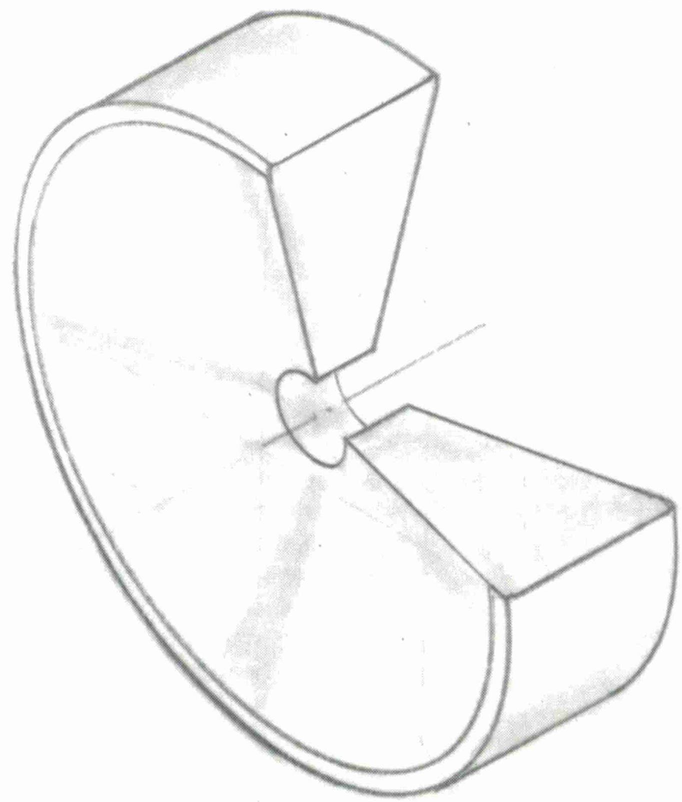

Figure 26. Composite road wheel #2.

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