Automatic Fabrication of Large Space Structures—The Next Step

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Introduction

MANY words have been devoted to what may be considered large space structures. They relate to a number of missions including resources and environment, communications, industrialization, energy, defense, and, finally, astronomy and planetary. For this paper, only the steps associated with energy and large space structures will be considered, as shown in Table 1. Current activities are shown as introductory steps to the last two decades of this century's space development. Note that each step takes us nearer to the ultimate goal of an operational 5-GW solar power satellite. The purpose of this paper is not to attempt to describe all of these steps, but that which is associated with only a single item within the concept depicted here. This single item is the machine which is used to produce the basic building-block beams used in the assembly of many of the large space structures.

A ground demonstration version of this machine has been completed. This aluminum beam builder (Fig. 1) is now in operation. Now that the feasibility of automatically producing beams has been successfully demonstrated, the question is, "What is the next step?" Following a brief description of the present beam builder, this paper will present an answer to this question, although not necessarily the only answer.

Ground Demonstration Aluminum Beam Builder

The aluminum beam builder shown in Fig. 1 is composed of the following subsystems:

1) Beam cap members are formed by three 7-station rolling mills, as shown in Fig. 2. These progressively form the longitudinal members of the beam from flat stock, as shown in this flower diagram. The flat stock is fed into the rolling mills from three reels, each holding 300 m of 0.4-mm-thick flat aluminum stock which can be replaced by another when depleted.

2) Beam cross brace storage and dispensing is provided by three sets of magazines which store the vertical and diagonal cross braces. Each magazine holds 200 cross braces, enough to make 300 m of beam. As with the aluminum feed reels, these can also be replaced with loaded magazines. The cross brace dispensing mechanism moves one cross brace into position to be picked up by a carriage mechanism which transports the cross brace from the magazine to the beam cap member.

3) Clamping and series spot welding of the cross brace is accomplished with a single mechanism. With the carriage mechanism holding the cross brace in place on the beam cap member, the weld block moves into place and clamps the cross brace to the beam cap member. At this time, the carriage mechanism releases the cross brace and retracts to its rest position ready to receive the next cross brace. With the weld block in position, the series spot weld cycle begins with each pair of electrodes being activated individually until six spot welds are accomplished at each end of cross brace, as shown in Fig. 3. It should be noted that all vertical cross braces are dispensed, clamped, and welded in place before the same sequence of events takes place for the diagonal cross braces.

4) Beam cutoff is accomplished once the desired length of beam has been produced. Three guillotines cut through the three beam cap members simultaneously.

5) Automatic control is accomplished with a simple commerical type computer which monitors all the functions of the beam builder. Each function, from rolling the proper length of the beam cap member to form one beam bay length

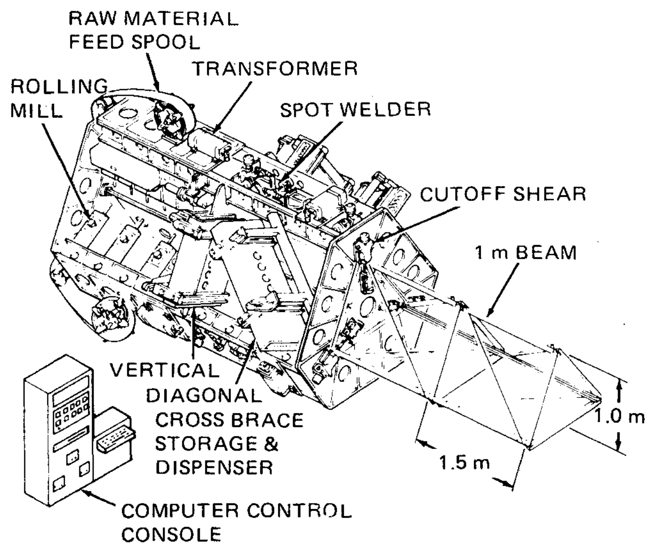

Fig. 1 Aluminum beam builder.

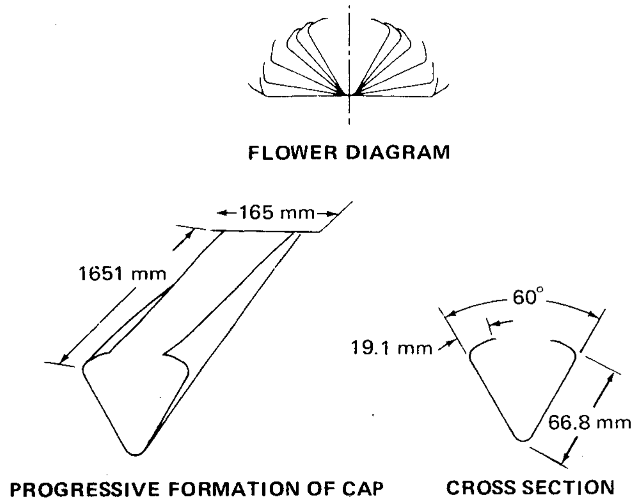

Fig. 2 Seven-station progressive roll form steps.

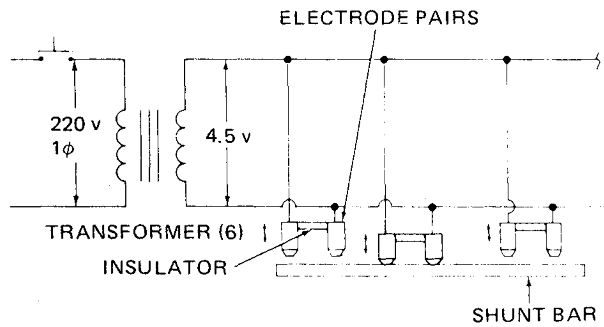

Fig. 3 Welding process schematic.

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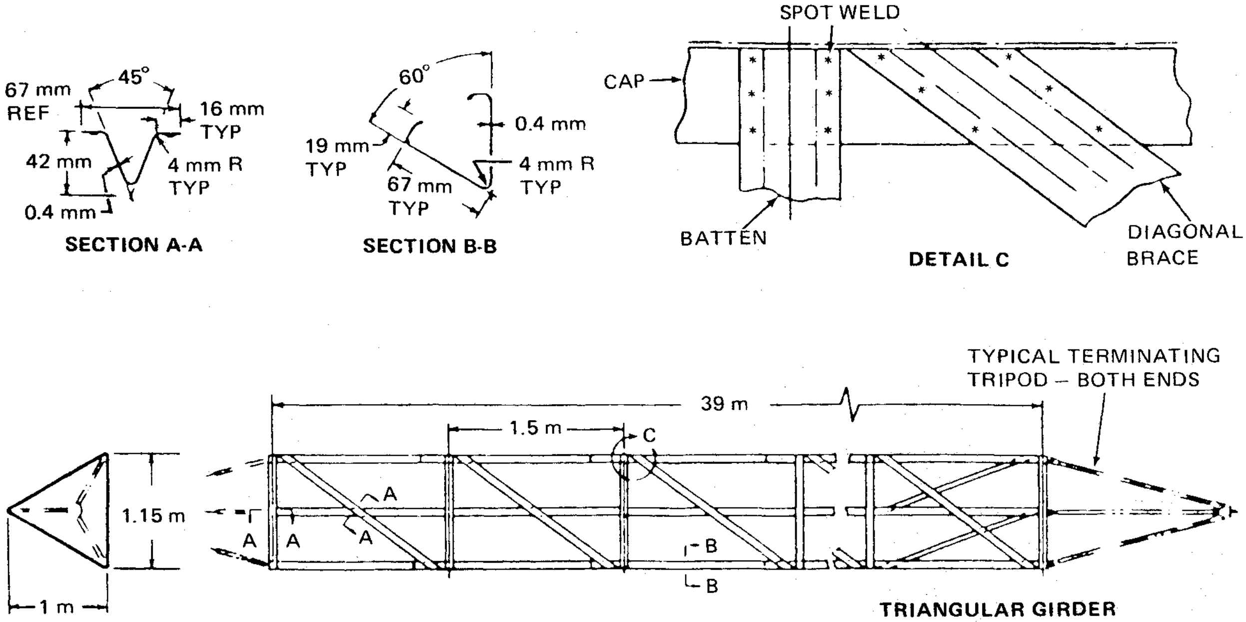

Fig. 4 1-m beam design.

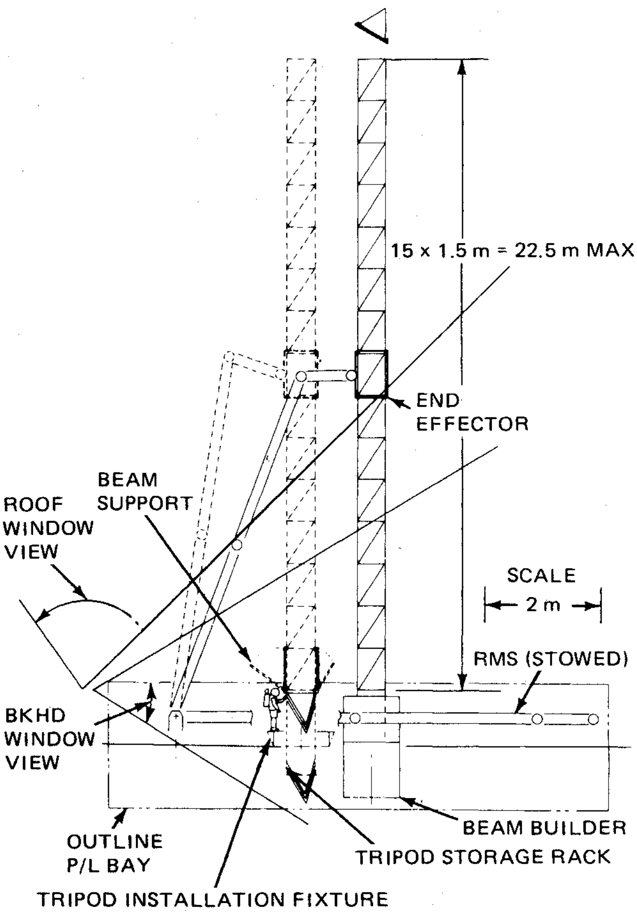

Fig. 5 Beam assembly support equipment.

(1.5 m) through cross brace dispensing, welding, and beam cutoff, is monitored and registered as completed before the next function is permitted to take place. This monitoring is accomplished by encoders, tachometers, photoelectric sensors and limit switches strategically placed throughout the machine.

Before answering the question presented in the introduction to this paper, "What is the next step?," it would seem appropriate to briefly describe the beam builder's product, (Fig. 4). The beam built has an equilateral triangular cross section 1-m deep. Each bay, measured from vertical cross brace to vertical cross brace, is 1.5-m long. All material used is 2024-T3 aluminum, 0.4-mm thick. The beam weighs 1.90 kg per bay length and has an operational design compressive load of 4003 N. A four-bay specimen has been tested to compressive load failure (failing at 6053N). This is quite an accomplishment for such a light structure.

Table 1 Steps toward accomplishing space solar power

Date	Step
1978	Beam builder (aluminum) demonstration
1979	First flight of space transportation article
1980	Beam builder (composite) demonstration
1981	Geosynchronous orbit environment satellite
1982	Flight-ready beam builder available
1983	Large space structure demonstration
1984	Spacelab—advanced technology lab
1985	Orbiting construction demonstration article—manned remote work station
1986	500 kW solar power development article
1987	Space construction base—manned
1988	Space manufacturing facility
1989	Advanced space construction base
1991	Geosynchronous orbit assembly and service development
1993-1995	50 MW solar power development article
1995-2000	5 GW solar power satellite

What Is the Next Step?

Having touched briefly on the steps toward the goal of a large space solar power satellite in the introductory remarks and shown graphically in Table 1, they will not be reviewed in detail.

Having developed the beam builder to fabricate the basic building-block beams required for a large space structure demonstration article, the next step is to know what special tools and equipment are required to accomplish the assembly of the structure. An assembly jig is required to support the structure while it is being assembled. The design and development of this jig is part of the next step. However, there are other hardware development items which have only been discussed superficially to date. These are all associated with handling the beam produced by the beam builder, installing tripod end fittings on both ends of each beam, and storing the tripods. Specifically, they are those support equipments needed to complete the basic building-block beam before it can be used to assemble a large space structure. Figure 5 constitutes the next step in hardware development.

RMS End Effector

In order to handle the beam produced by the beam builder, a special end effector for the Space Shuttle's remote manipulator system (RMS) will have to be developed; a simple grapple will not suffice. The fragility of the beam requires that the end effector lock onto a minimum of one bay length of the beam and softly engage the beam cap members to prevent local damage.

Tripod Installation Fixture

At one time, consideration was given to fastening the tripods to the ends of a beam as the beam was being produced by the beam builder. This would have required a considerable modification to the end of the machine. Further investigation and a desire for simplicity resulted in a separate tripod installation fixture located alongside the beam builder, providing the following features: 1) beam fabrication independent of, and simultaneous with, fastening of tripods to the beam; 2) single arrangement for locking and holding beam and tripod in place while fastening takes place; and 3) free access to either beam builder or fixture by astroworkers.

Tripod Storage Rack

To provide the number of beams required to assemble a typical large space structure, 42 tripods will be required. To effectively carry this number of prefabricated tripods into space aboard the Space Shuttle, it was concluded, after study, that finished tripods provided the most efficient stacking factor when stored in an appropriate storage rack. The most efficient arrangement is achieved by placing the installation fixture on top of the storage rack. The storage rack contains a feed mechanism which brings each tripod into its holding fixture position. For larger structures, additional storage racks would be required, which could include the tripod holding fixture feature or simply be used to replenish the one installed adjacent to the beam builder.

Conclusion

While one can argue the pros and cons of space solar power satellites, there is still general agreement that large structures in space will be required for other systems as well. Further, while one can argue the pros and cons of space-fabricated beam vs ground-fabricated erectables, whatever there configuration may be, it is generally agreed that, ultimately, space fabrication will be the most efficient way to build large space structures. Now that we have demonstrated the feasibility of automatically fabricating beams, the next step is to provide the tools necessary to successfully demonstrate assembly of a typical large space structure. These tools include: RMS end effector, tripod installation fixture, and tripod storage rack.

The time to begin the development of these tools is now.