Oct. 3, 1967 M. SULITEANU ETAL 3,344,631

MACHINE FOR SHAPING CURVED SURFACES

Filed June 17, 1965 3 Sheets-Sheet 1

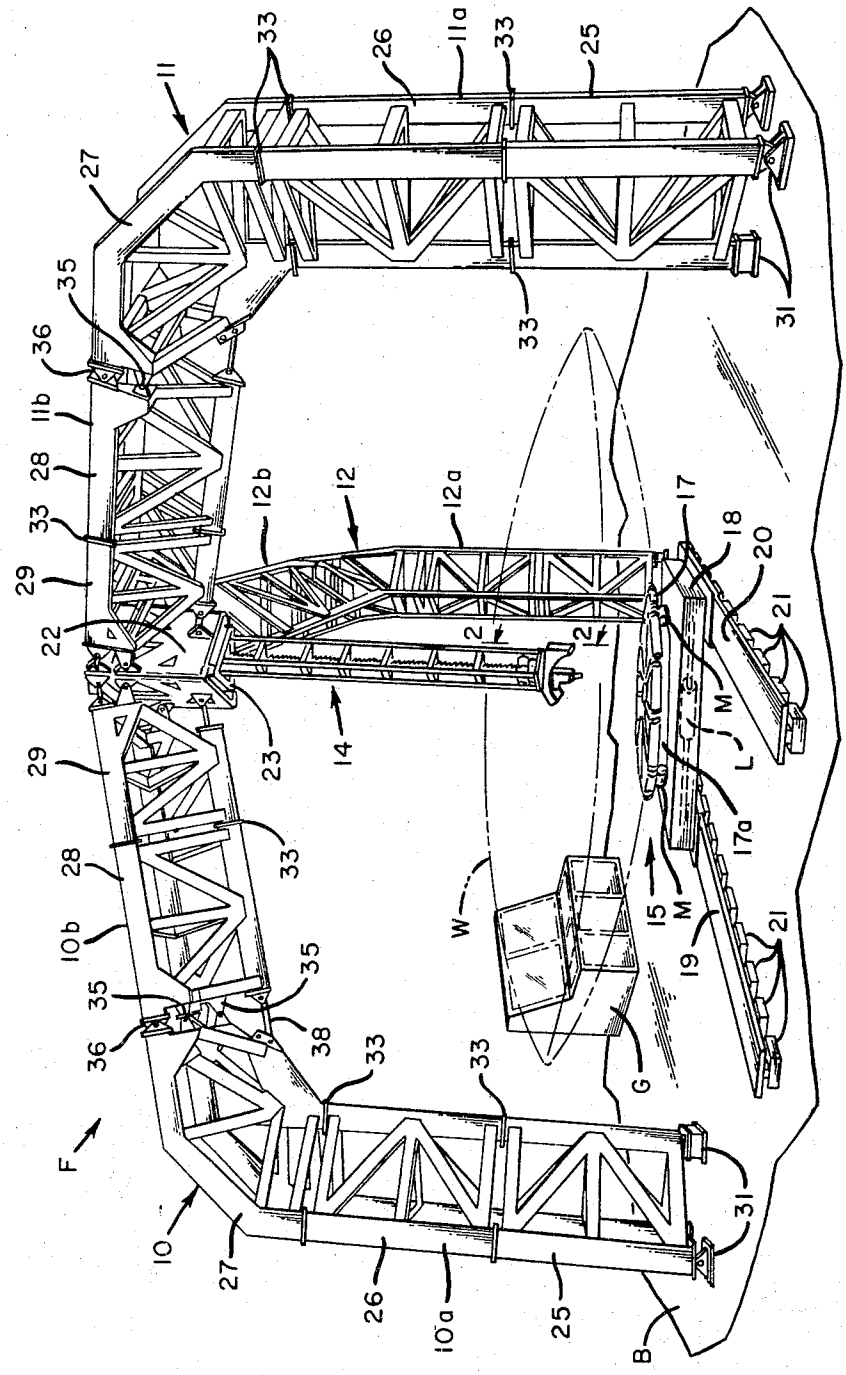


FIG-1

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Filed June 17, 1965 3 Sheets-Sheet 2

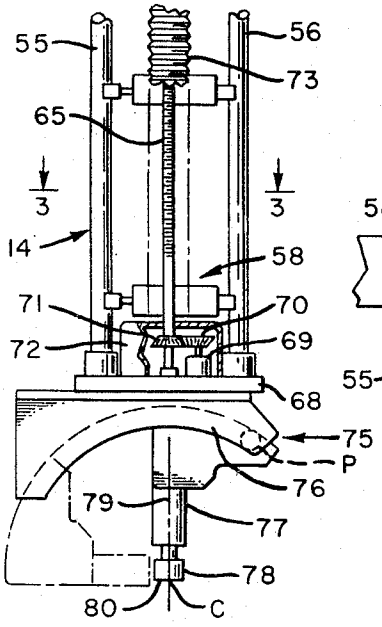


FIG-2

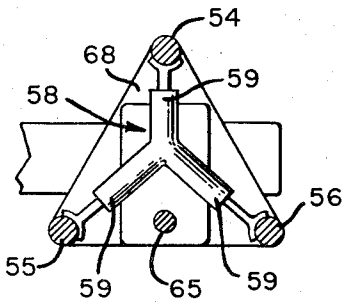


FIG-3

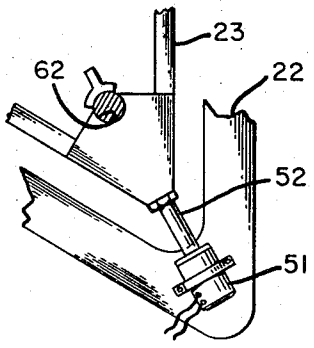


FIG-6

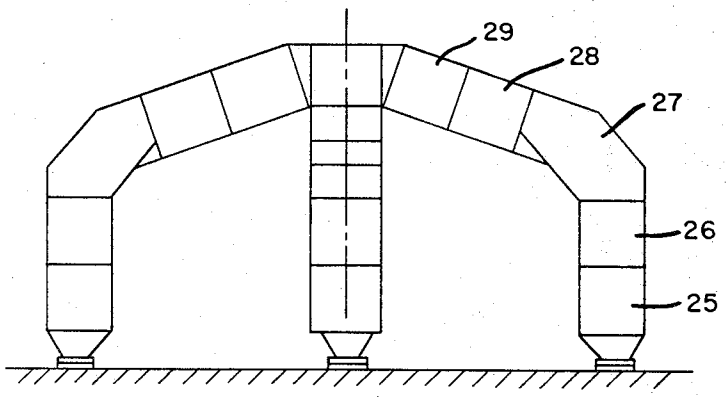


FIG-7

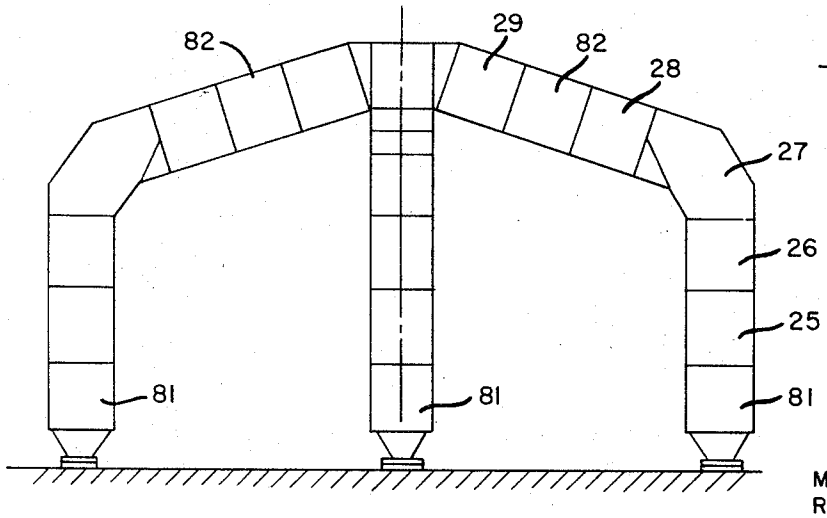


FIG-8

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MACHINE FOR SHAPING CURVED SURFACES

Filed June 17, 1965 3 Sheets-Sheet 3

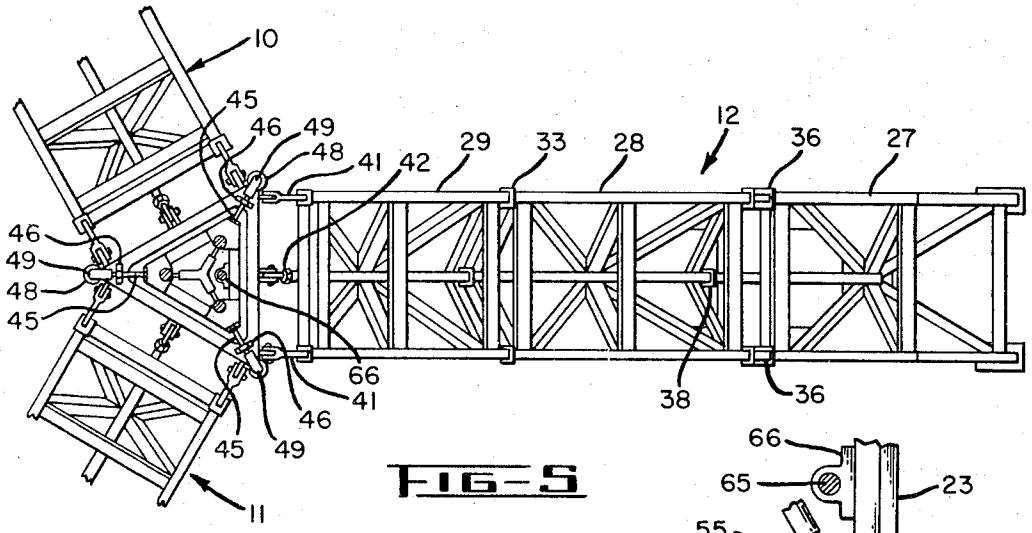


FIG-5

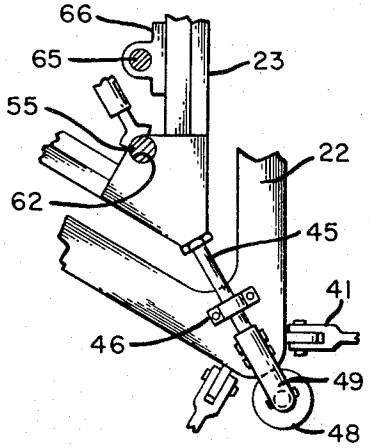


FIG-5-A

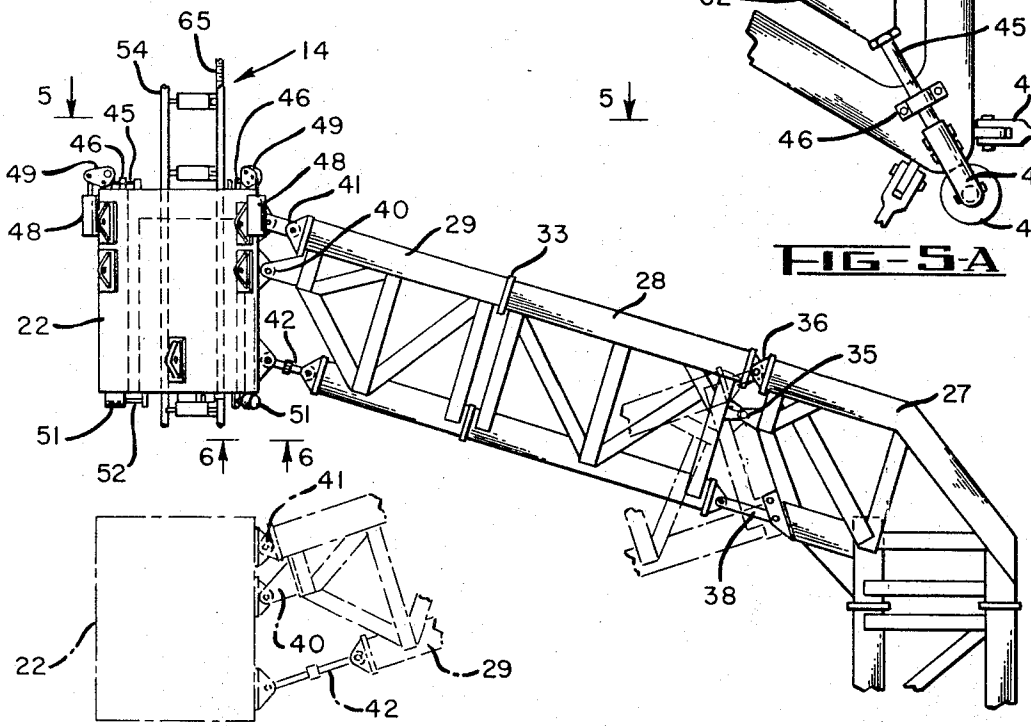


FIG-4

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United States Patent Office 3,344,631 Patented Oct. 3, 1967

3,344,631

MACHINE FOR SHAPING CURVED SURFACES

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9 Claims. (Cl. 72—7)

This invention relates to a forming machine for shaping or forming complexly curved objects such as parabolic dishes for antenna reflectors.

A problem in forming large unitary precision objects, such as parabolic reflectors for high gain antenna systems, is the size and complexity of the machine needed to perform the shaping operation. The precision with which the surfaces of such reflectors must be formed places extra-ordinarily high performance requirements on the machine which are met, inter alia, by increasing the mass and weight of the machine and its foundation. Because of the cost of the machine and the controlled conditions under which it must operate, the capacity of the machine is often limited to a particular size of workpiece, i.e., a mill designed to machine a 30-foot diameter reflector cannot readily be extended to machine a 60-foot diameter reflector. Such customized shaping machines thus lack versatility which is reflected in the high costs of such machines and the products made by them.

A general object of this invention is the provision of a machine capable of shaping large precision objects having a wide range of sizes.

Another object of the invention is the provision of such a machine that may be readily converted or changed to increase or decrease its workpiece size capacity.

The logistics in setting up ground based transmitting and receiving stations for space and satellite communications systems is complicated by the need for large precision antenna reflectors at remote sites. The size of unitary reflectors that can be shipped to the station from distant fabrication plants is limited by the physical capacity of modern transportation facilities. On the other hand, fabrication of such reflectors at the remote station involves a similar problem of transporting large, heavy precision machinery to the station and such on-site machining has the further disadvantage of requiring the costly and time-consuming installation of the machine together with its permanent foundation at the often remote location of the station.

An important object of the invention is the provision of such a machine having a modular construction which is readily assembled and disassembled into conveniently shippable units.

A further object is the provision of a modular shaping machine which is fully adjustable to permit precise alignment of the machine and the workpiece.

A further object is the provision of a shaping machine with a frame having legs made of substantially identical modules, the number of which determines the size and capacity of the machine.

These and other objects of the invention are accomplished with a machine having a tripod frame and a vertically movable tool supported at the apex of the frame. A workpiece on a turntable within and under the tripod is rotatable about a vertical axis and is movable along a horizontal axis which intersects the path of movement of the tool. Each tripod leg is made of separate interconnected modules, certain of which are identical to others in size and shape. Thus, a change in size of the machine to accommodate different sizes of workpieces is effected by changing the number of modules in the tripod legs. Precision alignment of vertical tool movement is achieved by adjustable positioning of an inner tool support cage relative to an outer cage, and leveling blocks for supporting each tripod leg and the workpiece turntable facilitate leveling of the machine. The cutting tool is pivotally supported in a tool head so that the cutting face of the tool may be adjusted to remain tangential to the machined surface of a complexly curved workpiece. Movements of the cutting tool and workpiece are programmed by a computer.

These and other objects of the invention will be understood from the following description of a preferred embodiment thereof, reference being had to the accompanying drawings in which:

FIGURE 1 is a perspective view of a shaping machine embodying the invention;

FIGURE 2 is an enlarged elevation of the lower part of the vertical boom as viewed on line 2—2 of FIGURE 1 and showing the tool head assembly;

FIGURE 3 is a transverse section taken on line 3—3 of FIGURE 2;

FIGURE 4 is a side elevation of the upper part of the machine showing the connection of the outer cage to the tripod legs;

FIGURE 5 is a top view of the upper part of the machine as viewed on line 5—5 of FIGURE 4;

FIGURE 5-A is an enlarged portion of FIGURE 5 showing the connection of the inner and outer cages;

FIGURE 6 is an enlarged bottom view of part of the outer and inner cages taken on line 6—6 of FIGURE 4 and showing the cage locking mechanism; and

FIGURES 7 and 8 are schematic elevation views of the tripod frame illustrating the manner in which the size of the frame is increased by the addition of modules to the tripod legs.

Referring now to the drawings, a machine embodying the invention is illustrated in FIGURE 1 and comprises a tripod frame F having three legs **10**, **11** and **12** which support a vertically movable boom **14** on a base B over a workpiece support assembly **15**. Assembly **15** comprises a turntable **17** having a drum **17***a* engaged by a drive mechanism M for rotating the turntable about a vertical axis. A workpiece W, shown in broken lines as a convexly curved antenna, is adapted to be supported on the turntable. A carriage **18** supports the turntable on parallel tracks **19** and **20** and carries a drive motor L which controls the extent and rate of movement of the turntable assembly in a horizontal plane. The shaping of the workpiece is accomplished by precision control through a computer G which synchronizes and governs the rate of vertical feed of boom **14**, the speed of rotation of turntable **17** and the rate of horizontal movement of carriage **18** along the tracks **19** and **20**. In order to permit leveling of tracks **19** and **20**, leveling blocks **21** are provided to support the tracks on base B.

Legs **10**, **11** and **12** of the tripod frame are substantially identical and have vertical parts **10***a*, **11***a* and **12***a* supported on base B and upper converging parts **10***b*, **11***b* and **12***b* which connect at their inner ends to a housing or outer cage **22**. A boom supporting inner cage **23** is mounted on and within the outer cage **22** and is laterally adjustable relative thereto in order to effect vertical alignment of the boom as described in detail below.

The tripod legs **10**, **11** and **12** are substantially identical in construction and therefore only one leg will be described in detail in the following discussion, like reference characters indicating like parts on the drawings. Each leg is made of a plurality of frame units or modules **25**, **26**, **27**, **28** and **29** removably secured together. These modules are composite structures preferably having triangular shaped cross-sectional profiles; each module has an open-type construction to minimize the weight, and comprises longitudinal, cross and diagonal struts preferably made of rigidized foam.

Modules **25** and **26** are secured together in stacked relation to form the lower part of the leg. Bottom module **25** is connected to base B by leveling pads **31** which permit vertical adjustment of each corner of the module for leveling the tripod frame on the base. Adjacent faces of the modules are connected by coupling plates **33** which are secured together by bolts or the like. Corner module **27** is constructed to provide a bend in the leg of an angle of approximately 55 to 60° from horizontal. Modules **25, 26** and **28** in each leg are identical in size and shape and are therefore interchangeable. End module **29** is directly connected to outer cage **22** which therefore couples the upper ends of the three frame legs together.

In order to adapt the machine to accommodate workpieces having different heights, the upper parts of each leg may be alternately secured on the corner module **27** to extend downwardly therefrom for supporting the carriage and boom assemblies at the lower position as shown in broken line in FIGURE 4. To this end, module **28** is connected to the corner module **27** by pivot plates **35** located between the top and bottom sides of modules **27** and **28**. The top side of module **28** is connected to the corner module **27** by coupling plates **36** and the lower part is connected to the corner module by an elongated link **38**. The lower part of the inner face of corner module below hinge plates **35** is inclined rearwardly as shown to permit downward pivoting of module **28** relative to the corner module **27** about pivot plate **35** to the lower position. Similarly, end module **29** is connected to the outer carriage by pivot plates **40** located intermediately of upper and lower coupling links **41** and **42**, respectively, and the inner face of module **29** is angularly shaped as shown. When it is desired to move the outer carriage (and thus the boom) to the lower operating position, upper links **36** and **41** and lower links **38** and **42** on modules **28** and **29**, respectively, of each leg are removed, the upper leg parts together with the outer cage are lowered to the broken line position shown in FIGURE 4 with the parts pivoting about pivot plates **35** and **40**, and the coupling links are replaced with others of appropriate length to again secure the upper and lower parts of the modules and cage together.

The outer and inner cages **22** and **23** comprise three-sided open-ended housings. Inner cage **23** is adjustably supported on the outer housing by three links **45**, see FIGURES 5 and 5–A, secured at their inner ends to the top corners of the inner cage and slidably mounted in bearing brackets **46** on the top of the outer cage. Links **45** are movable in directions transversely of the vertical axis of the cage and along lines which converge at angles of 120°. Synchronized movement of the links **45** along these lines effects adjustment of the position of the inner cage relative to the outer cage and is accomplished by servo motors **48** connected to the links by cranks **49**. Energization of motors **48** through appropriate controls permits movement of the inner cage relative to the outer cage in any direction in the transverse or horizontal plane to effect vertical alignment of the boom.

Three remotely actuated lock mechanisms **51**, see FIGURES 4 and 6, on the lower corners of the outer cage have extensible arms **52** which engage the respective corners of the inner cage. When each lock mechanism is released, arms **52** move freely to permit unimpeded relative movement of the cages. After boom alignment is completed, locks **51** are actuated, and each arm **52** is clamped so that the inner cage is secured in the adjusted position with respect to the outer cage.

Boom **14** comprises three elongated parallel rods **54, 55** and **56**, see FIGURES 2 and 3, secured together at vertically spaced positions by a plurality of Y-shaped brackets **58**. Each bracket has arms **59** spaced 120° apart and connected to the inside portions of the respective rods for substantially less than 180° of the rod surface. The outside parts of the rods are slidably mounted in circularly shaped bearings **62**, see FIGURES 5–A and 6, located at the inside corners of the inner cage **23**. In order to provide maximum support for the boom, the bearings **62** preferably engage more than 180° of the surface of the respective rods and a length thereof corresponding to the height of the inner and outer cages.

Feed screw **65** is coextensive with the boom and extends between aligned arms **59** of the several brackets **58** for engagement with a fixed nut **66**, see FIGURES 5 and 5–A, secured to the inner surface of inner cage **23**. The screw is journaled on plate **68** at the lower end of the boom and is rotated by a motor **69**, see FIGURE 2, on plate **68** through gears **70** and **71**. A housing **72** protectively covers this screw drive mechanism. A bellows-like cover **73** over screw **65** protects the same from dirt and foreign matter. Vertical movement of the entire boom within the inner carriage is thus accomplished by rotation of screw **65** by feed motor **69**.

A tool head assembly **75** is mounted on bottom plate **68** of the boom and comprises a frame **76** secured to the plate, and a tool holder **77** supported on the frame. A cutting tool **78** is rotatably supported on the end of the holder, is driven to rotate about the axis **79** of the holder and has a cutting surface **80** at its lower extremity. In order that the cutting surface **80** of the tool **78** is at all times tangential to the surface of a curved object being cut, tool holder **77** is supported in the frame **76** for pivotal movement about the center C of the cutting surface between the solid and broken line positions shown in FIGURE 2. A motor P within frame **76** effects such pivotal movement of the tool holder which is also precisely controlled by the computer G in synchronism with the feed movements of the boom and workpiece turntable.

The operation of the machine will now be explained. The machine is initially set up by clamping modules together to keep the frame with the upper parts **10***b*, **11***b* and **12***b* of the tripod legs connected through the outer cage **22** in the upper or lower position as desired. Outer cage **22**, inner cage **23** and boom **14** preferably are assembled as a subassembly prior to connection to the inner ends of the tripod legs. The tripod frame is then leveled by use of leveling pads **31** and vertical alignment of boom **14** is effected by adjustment of the position of the inner cage relative to the outer cage by servo motors **48**. The cages are then locked by lock mechanisms **51**.

Turntable **17**, carriage **18** and tracks **19** and **20** are leveled by means of leveling jacks **21** under the tracks so that the axis of rotation of the workpiece on the turntable moves in a vertical plane containing the center point on the face of the cutting tool when carriage **18** moves over the tracks. The turntable with the workpiece mounted thereon is then positioned under the cutting tool such that initially the axis of rotation of the turntable passes through the center point C on the cutting face of the tool. The boom is then lowered through the action of feed screw **65** until the tool is adjacent to the body of the workpiece to be formed. The computer G is programmed to control vertical feed of the boom, i.e., screw motor **69**, the angular velocity of the turntable, the rate of feed of the turntable carriage along tracks **19** and **20**, and the angular displacement of tool holder **77**. As these feed movements of the machine are related by the computer, the cutting tool **78** removes material initially from the workpiece at its center of rotation and progressively outwardly therefrom as the turntable carriage **18** moves along tracks **19**. Simultaneously, the boom moves vertically and the tool holder **77** pivots to maintain tangential relationship between the cutting tool and the surface being formed.

A unique feature of the shaping machine is the ease, convenience and economy with which the size of the tripod frame may be changed to accommodate different sizes of workpieces. This versatility of the machine is illustrated in FIGURES 7 and 8 wherein the height of the outer cage above the base B is increased simply by the addition of one or more modules **81** to the lower

parts of the tripod legs and the lateral spacing of the legs is similarly increased by the addition of one or more modules **82** to the upper parts of the legs. The symmetry of the machine together with the unique modular construction of the frame and the identical size and shape of modules **25**, **26** and **28** facilitate variation in the capacity of the machine readily without altering the basic design.

The modular construction of the machine frame also permits disassembly and shipment of the machine in convenient transportable units. The provision for leveling of the frame and tracks together with provisions for alignment of the boom facilitates set up of the machine at remote sites on compact inexpensive foundations.

Changes, modifications and improvements may be made by others to the above-described embodiment of the invention without departing from the spirit and scope of the invention. For example, tool holder **77** may comprise a mechanism for depositing material on the workpiece to a controlled thickness and may include spray guns for projecting metal or foamed plastic substances. Therefore the appended claims describe the novel features of the invention.

We claim:

1. A machine for forming objects comprising
- a tripod frame having three legs adapted to rest on a base at spaced locations and converging to a common connection above the base,
- an elongated vertically extending boom supported for vertical movement at said common connection and having a forming tool at the lower end thereof,
- a turntable assembly under and within said legs adapted to support a workpiece and comprising
  - track means on said base,
  - a carriage supported for lineal movement along said track means in a direction transversely of the direction of movement of said boom, and
  - a turntable mounted on said carriage for rotation about a vertical axis, and
- means for synchronizing the movements of said boom and said carriage and said turntable whereby said tool forms said workpiece to a predetermined shape.

2. A machine for forming objects comprising
- a frame having at least three legs adapted to rest on a base at spaced locations and converging to a common connection above the base,
- a forming tool supported at said common connection for vertical movement,
- a turntable assembly under and within said legs adapted to rotatably support a workpiece and supported on said base for lineal movement in a direction transversely of the direction of movement of said forming tool, and
- means for synchronizing the movements of said tool and said turntable assembly whereby said tool forms the workpiece to a predetermined shape.

3. The machine according to claim **2** in which each of said frame legs comprises a plurality of modules removably secured together.

4. The machine according to claim **3** in which certain modules in each leg are substantially identical.

5. The machine according to claim **3** in which each frame leg has a vertically extending lower portion and an upper portion, and means for securing the end modules of said upper leg to adjacent parts of the frame to support said tool at more than one elevation above the turntable assembly.

6. A machine for forming objects to a predetermined shape comprising
- a tripod frame having three substantially identical legs adapted to rest at spaced locations on a base and converging toward each other to a position substantially above the base with equal angular spacing of the legs,

- means for vertically adjusting each leg relative to the base,
- an outer cage secured to the upper ends of the converging legs,
- an inner cage adjustably supported on the outer cage for transverse movement relative thereto and having a fixed nut secured thereto,
- motor means on the outer cage operatively connected to the inner cage for adjusting the position of the latter relative to the outer cage,
- means for clamping the inner cage in fixed position relative to the outer cage,
- an elongated vertically extending boom comprising
  - a plurality of rods slidably supported for vertical movement by and within said inner cage,
  - an end plate secured to the lower ends of said rods,
  - a feed screw coextenssive with said rods and engaging said nut and rotatably secured to said end plate; and
  - motor means supported by said rods for rotating said screw relative to said nut whereby to vertically displace said rods,
- a tool head assembly secured to said end plate and comprising a forming tool at the lower extremity,
- a turntable assembly under and within said legs comprising
  - track means extending under said boom along said base,
  - jacks adjustably supporting said track means on said base,
  - a carriage mounted on said track means,
  - means for moving said carriage along said track means,
  - a turntable supported on said carriage for rotation relative thereto about a vertical axis,
  - means for rotating said turntable about said vertical axis, and
- computer means for controlling actuation of said screw rotating motor means and said carriage moving means and said turntable rotating means whereby movement of a workpiece on said turntable relative to said forming tool is controlled to form said workpiece to a predetermined shape.

7. The machine according to claim **6** in which said tool head assembly includes a frame and a tool holder mounted on said frame and supporting said forming tool, and means for moving said tool holder relative to said frame whereby the tool is pivoted about its end to alter its positional relationship with the workpiece surface.

8. A machine for forming objects to a predetermined shape comprising
- a tripod frame having three substantially identical legs adapted to rest at spaced locations on a base and converging toward each other to a position substantially above the base with equal angular spacing of the legs,
  - each of said legs comprising a plurality of modular structure elements removably secured together,
- means for vertically adjusting each leg relative to the base,
- an outer cage secured to the upper ends of the converging legs,
- an inner cage adjustably supported on the outer cage for transverse movement relative thereto and having a fixed nut secured thereto,
- an elongated vertically extending boom comprising
  - a plurality of rods slidably supported for vertical movement by and within said inner cage,
  - a feed screw coextensive with and secured for movement with said rods and engaging said nut, and
  - motor means supported by said rods for rotating said screw relative to said nut whereby to vertically displace said rods relative to the inner cage,
  - a tool head assembly mounted at the lower ends of

the rods and comprising a forming tool at the lower extremity,

a turntable assembly under and within said legs comprising

track means extending under said boom along said base,

jacks supporting said track means on said base,

a carriage mounted on said track means,

means for moving said carriage along said track means,

a turntable supported on said carriage for rotation relative thereto about a vertical axis,

means for rotating said turntable about said vertical axis, and

computer means for controlling actuation of said screw rotating motor means and said carriage moving means and said turntable rotating means whereby a movement of a workpiece on said turntable relative to said forming tool is controlled to form said workpiece to a predetermined shape.

9. A machine for shaping complexly curved objects comprising

a frame having at least three legs adapted to rest at spaced locations on a base and converging toward and supported on each other at a junction substantially above the base,

an elongated vertically extending boom comprising

a plurality of rods slidably supported for vertical movement at the junction of said frame legs,

a feed screw movable vertically with and rotatable relative to said rods and engaging said nut, and

motor means carried on said rods for rotating said screw relative to said nut whereby to vertically displace said rods,

a tool head assembly comprising

a frame,

a tool holder movably supported on said frame,

a forming tool mounted on said holder at the lower extremity thereof, and

means for moving said holder and tool relative to said frame whereby the tool is pivoted about its end to alter its positional relationship with the workpiece surface,

a turntable assembly under and within said legs comprising

track means extending under said boom on said base,

a carriage mounted on said track means,

means for moving said carriage along said track means,

a turntable supported on said carriage for rotation relative thereto about a vertical axis,

means for rotating said turntable about said vertical axis, and

computer means for controlling actuation of said screw rotating motor means and said tool holder moving means and said carriage moving means and said turntable rotating means whereby a movement of a workpiece on said turntable relative to said forming tool is controlled to form said workpiece to a predetermined shape.

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