

[54] APPARATUS AND METHOD FOR
CREATING THREE-DIMENSIONAL
OBJECTS

[75] Inventor: S. Scott Crump, Minnetonka, Minn.

[73] Assignee: Stratasys, Inc., Minneapolis, Minn.

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[58] Field of Search 364/472, 473, 477;
264/308, 113; 425/174.4; 427/8, 52; 164/94;
239/75, 82, 83, 84, 132

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Primary Examiner—Joseph Ruggiero

Assistant Examiner—Patrick D. Muir

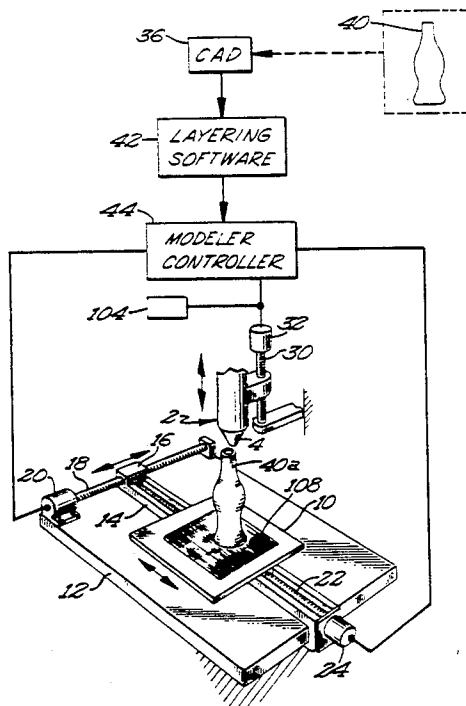
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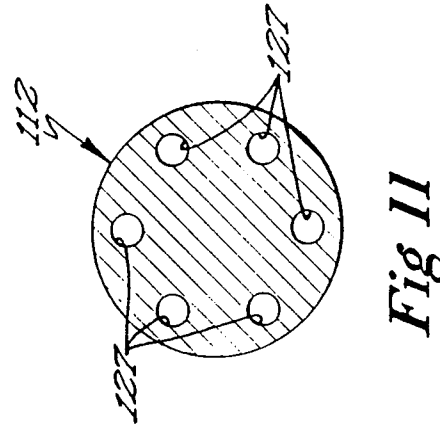
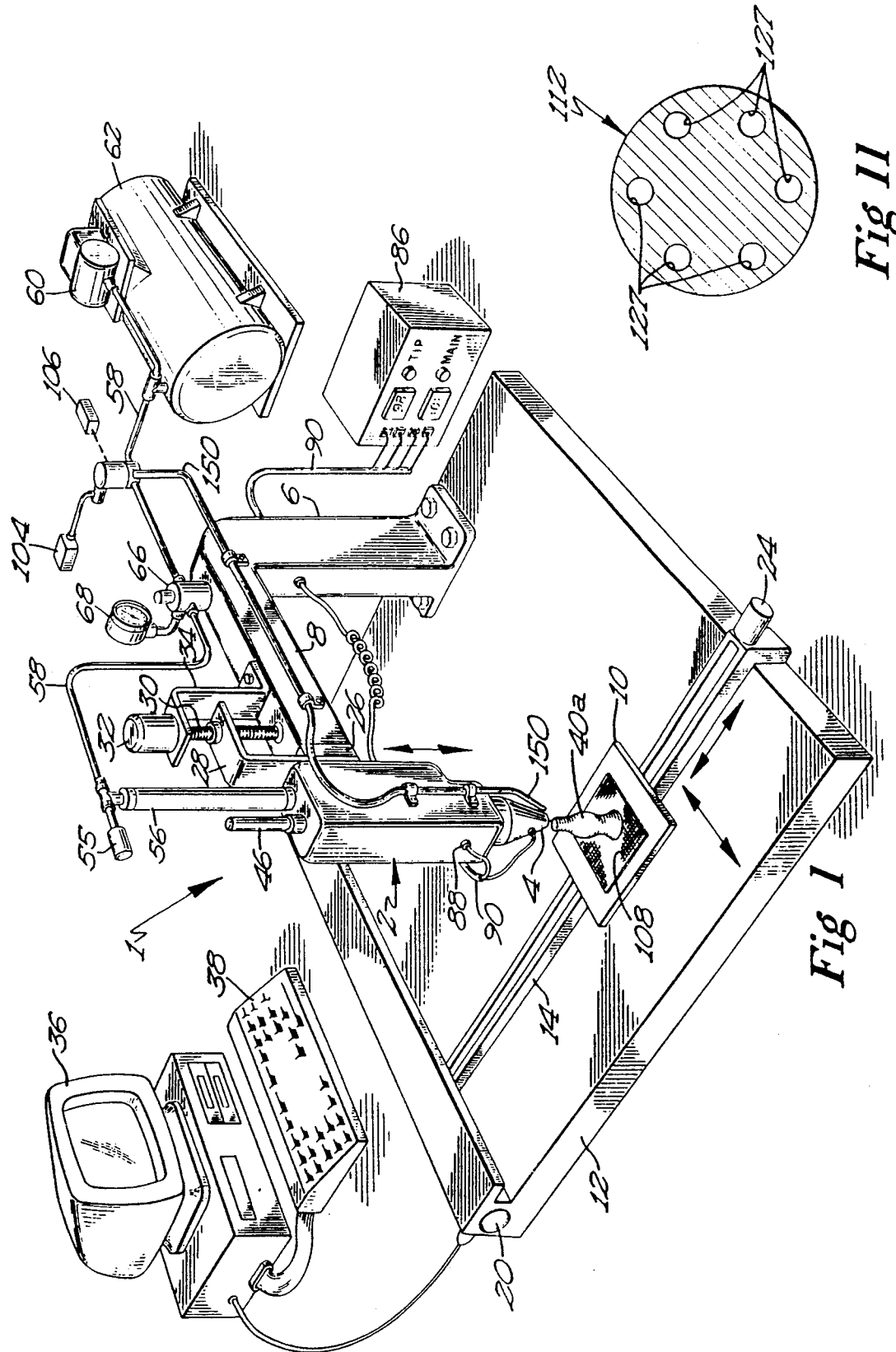
[57] ABSTRACT

Apparatus incorporating a movable dispensing head provided with a supply of material which solidifies at a predetermined temperature, and a base member, which are moved relative to each other along "X," "Y," and "Z" axes in a predetermined pattern to create three-dimensional objects by building up material discharged from the dispensing head onto the base member at a controlled rate. The apparatus is preferably computer driven in a process utilizing computer aided design (CAD) and computer-aided (CAM) software to generate drive signals for controlled movement of the dispensing head and base member as material is being dispensed.

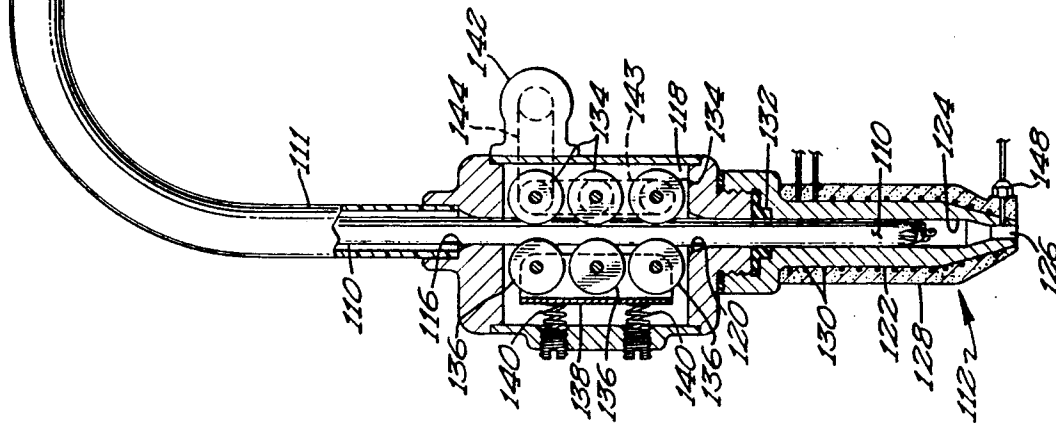
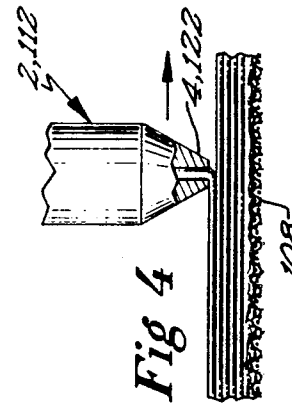
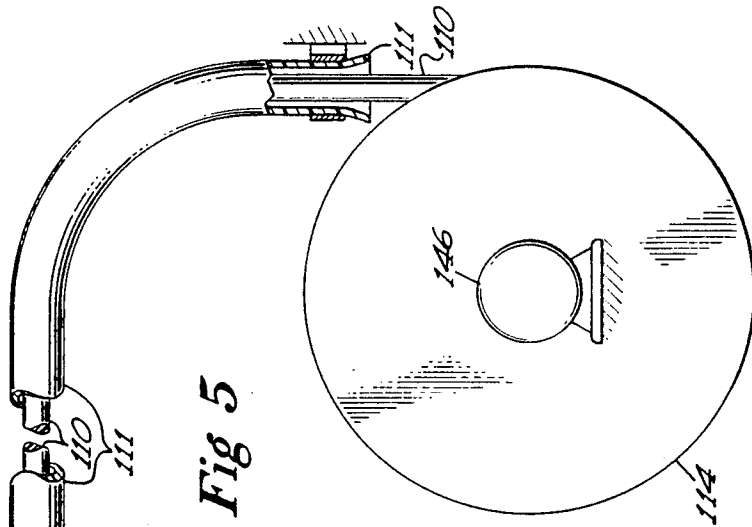
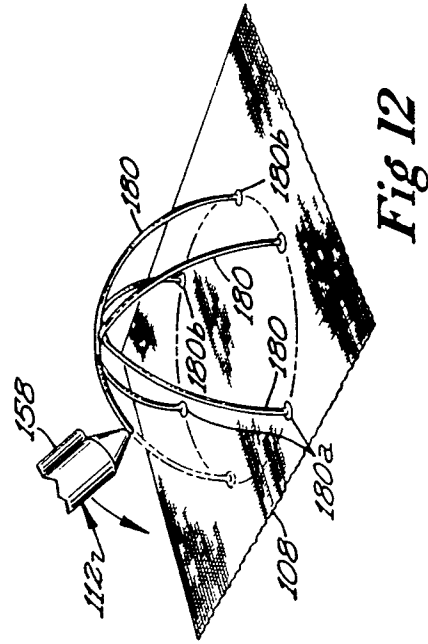
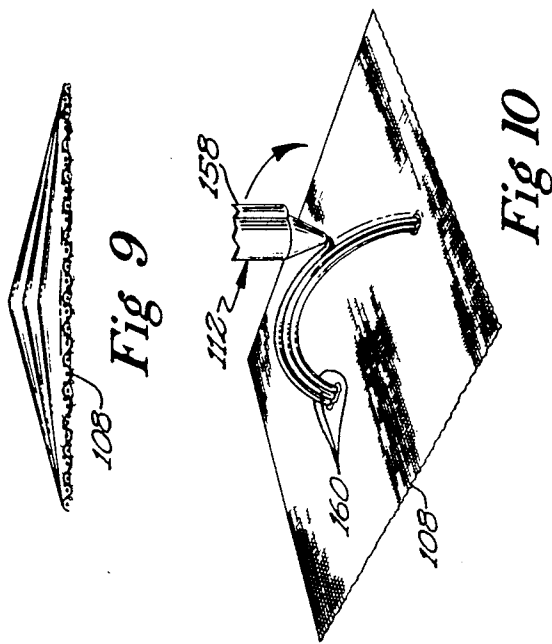
Three-dimensional objects may be produced by depositing repeated layers of solidifying material until the shape is formed. Any material, such as self-hardening waxes, thermoplastic resins, molten metals, two-part epoxies, foaming plastics, and glass, which adheres to the previous layer with an adequate bond upon solidification, may be utilized. Each layer base is defined by the previous layer, and each layer thickness is defined and closely controlled by the height at which the tip of the dispensing head is positioned above the preceding layer.

44 Claims, 3 Drawing Sheets









APPARATUS AND METHOD FOR CREATING THREE-DIMENSIONAL OBJECTS

BACKGROUND OF THE INVENTION

This invention relates to an apparatus and process for forming a three-dimensional object of predetermined design, and in particular to the making of a model or article by depositing multiple layers of a material in a fluid state onto a base. The material is selected and its temperature is controlled so that it solidifies substantially instantaneously upon extrusion or dispensing onto a base, with the build-up of the multiple layers forming the desired article.

Methods and techniques for making three-dimensional articles of a predetermined size and shape are known. In accordance with conventional techniques, the desired part is initially drawn, either manually or automatically utilizing a computer-aided design (CAD) procedure, with the article being ultimately formed by removing material from a block workpiece to form the desired shape in a machine operation. The machining operation may also be automatic with the utilization of a computer-aided machining (CAM) process. This costly and time consuming process is repeated multiple times to perfect the final manufacturing of a part, model, or prototype. The designer's success is often dependent upon either the interpretation or the skill of the machinist making the prototype or model. This common practice of mechanically removing material to create three-dimensional objects involves significant machining skills and machining time. Chemical machining techniques available to form objects have depth limitations and are incapable of making complex shapes. Thermal molding by injection or other molding techniques requires expensive molds and a procedure better adapted economically for large runs where reproducibility is required. With respect to jewelry applications, most custom jewelry is now produced manually.

The current state of the art does embrace processes for making three-dimensional objects by building-up material in a pattern as prescribed by an article to be formed. U.S. Pat. No. 4,665,492 issued to William E. Masters discloses such a process wherein a stream of particles is ejected from a supply head and directed to the coordinates of the three-dimensional article in response to data automatically provided from a CAD system. This process requires a seed at the point of origin of the article to which the particles are initially directed. The particles impinge upon and adhere to each other in a controlled environment so as to build-up the desired article. The Masters procedure requires the use of two injection heads to achieve the desired three-dimensional article, requires a seed at the point of origin about which the article is constructed, and thus does not lend itself to the formation of successive layers of material in a predetermined pattern as a relatively simple means for building-up an article, such as a model or prototype. The Masters system builds up the article from a central seed by applying material to predetermined coordinates. Such a process presents inherent difficulties in holding close tolerances in the 0.001 inch range and without accumulative error build-up.

Processes and apparatus also exist in the prior art for producing three-dimensional objects through the formation of successive, adjacent laminae which correspond to adjacent cross-sectional layers of the object to be formed. However, known techniques of that type in

the art of stereolithography require the use of a vat of liquid comprising a photocurable polymer which changes from a liquid to a solid in the presence of light. A beam of ultraviolet light (UV) is directed to the surface of the liquid by a laser beam which is moved across the liquid surface in a single plane, in a predetermined XY pattern, which may be computer generated by a CAD system. In such a process the successive layers may only be formed in a single, horizontal plane, with successive layers which solidify in the liquid vat adhering together to form the desired object. Such a process and apparatus is disclosed in U.S. Pat. No. 4,575,330 issued to Charles W. Hull.

U.S. Pat. No's. 4,752,498 and 4,801,477 issued to Fudim disclose more recent methods for the production of three-dimensional objects by irradiation of photopolymers within a liquid medium. Multi-layered objects can be made in accordance with the teachings of those patents by directing photopolymer solidifying radiation directly into a desired area within the uncured photopolymer with the use of an immersed radiation guide. However, here again, such processes require the use and handling of curable photopolymer liquids which are hazardous, and do not permit the forming of ultrathin layers of material in building up an object with a very fine and smooth surface.

U.S. Pat. No. 4,818,562 issued to Frank G. Arcella et al discloses a method form forming an article by directing a laser beam to a fusible powder which is melted by the beam and solidifies on its surface to form an object of desired shape. This process is also very expensive, and is further complicated by the required use of a gas which is directed through the powder to fluidize it. Impurities in the gas must ultimately be removed, and the gas must be recirculated or vented by the use of complex gas-handling apparatus.

Devices also exist for the manual making of models or sample articles, such as jewelry, from wax by the use of a wax dispensing gun from which the wax is dispensed in a heated, molten state. Such a wax-modeling gun is manufactured by the MATT Company, 663 Fifth Avenue, New York, N.Y. Also, glue guns, such as that manufactured by Parker Manufacturing Company of Northboro, Mass., are available for heating and dispensing adhesives in a fluid, molten state for gluing articles together. The Parker glue gun utilizes a glue stick which is heated within the gun and dispensed as a melted glue. However, neither the wax-molding gun nor the known glue guns have ever been adapted or utilized in conjunction with mechanical means through which the dispensing gun and/or a substrate may be mechanically moved with respect to each other so as to generate a predetermined, three-dimensional shape by applying successive layers of material in a predetermined pattern.

Thus, a need continues to exist for a relatively simply and efficient process and apparatus by means of which designers may design and create three-dimensional objects at office work stations. The process and apparatus disclosed herein meets that need with the same ease and simplicity of using a desk-top computer and printer, with the entire modeling process being carried out at the operator's CAD work station.

BRIEF SUMMARY OF THE INVENTION

This invention has as its primary objective the provision of a process and apparatus by means of which

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