Automated finishing of steel castings

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The task of metal removal from steel castings may often be repetitive, and has to be carried out in the unpleasant environment of cleaning rooms. To achieve improved productivity in metal removal, an automation concept has been developed and a machine designed to implement that concept.

DURING THE last two decades, manufacturing productivity in steel foundries has increased through application of new technology and automation such as parts interchangability, NC machining equipment, and programmable industrial robots. Since the finishing operations of steel castings are labour intensive and have to be carried out in the unpleasant environment of cleaning rooms, further improvements in productivity and cost reduction can be achieved by programmable automation.

Cleaning and finishing operations of steel castings involve a wide range of mechanical and metallurgical engineering technology. These operations include taking out of sand from castings, removal of risers, runners and pads, repair of random holes, heat treatment before or after cleaning, etc., and may be characterised by: quality of the finished parts; quantity of parts produced per pattern; and weight and geometry of parts produced. Typical processes used are air hammer clipping, sledge hammer flogging, shot blast cleaning, air-arc and torch cutting, welding, grinding, tabor saw cutting, etc.[1] Flexible and multipurpose machines facilitate handling castings of different geometric configurations as well as provide better scheduling of material flow.

As a proof-of-concept, a computer-controlled cutting machine with a flexible clamping device has been designed, built, and tested. The machine is easily programmable, and is capable of executing complex movements associated with clamping and metal cut-off operations at satisfactory speed and accuracy. To operate the machine, a human operator initially uses manual control on a particular casting. This is the TEACH mode when the computer memorizes the machine movements to copy them for castings of identical pattern in the subsequent REPEAT modes.

Description of the machine

The machine consists of a table positioning system and a cut-off mechanism. The positioning system incorporates a Bridgeport rotary table mounted on top of a Thomson T/C Mill-Drill table, Model 100, which has orthogonal motion capability. The cut-off mechanism is a Craftsman radial arm saw, Sears Model 113.23111, mounted above the positioning table. The entire assembly is mounted on a bench. The required control system equipment, with the exception of the computer, is mounted on or within the moveable assembly.

The saw has a 10 inch (254 mm) blade driven by a 2 hp (1.5 kw output) motor with a maximum cutting length of 18½ inches (470 mm). The radial arm can be moved and locked in any angular position. The motor can be tilted from 0 to 90 degrees from the vertical axis and can accept various attachments such as end mills and surface planers. The height of the saw can be manually adjusted.

The rotary table is 12 inches (305 mm) in diameter and has a rotational capability of ± 360 degrees. The Mill-Drill table can move in any direction in the horizontal plane, and is capable of handling weights up to 500 lbs. (227 kg). It has a total travel of 12 inches (305 mm) from side to side (x-direction) and 10 inches (254 mm) from front-to-back (Y-direction). The assembly of rotary table and X-Y positioning device has three degrees of freedom as shown in Fig. 1.

The X-Y positions and feed motion of the saw are controlled by PRINCE double acting hydraulic cylinders each

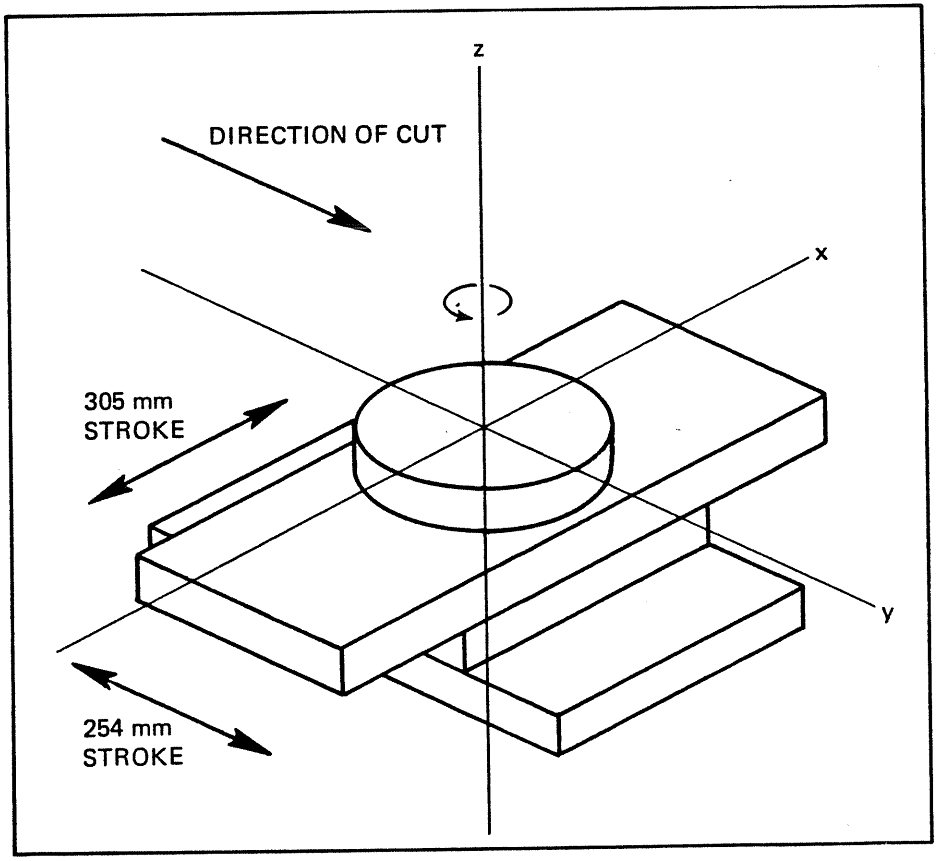

Fig. 1 Degrees of Freedom of Table Movements

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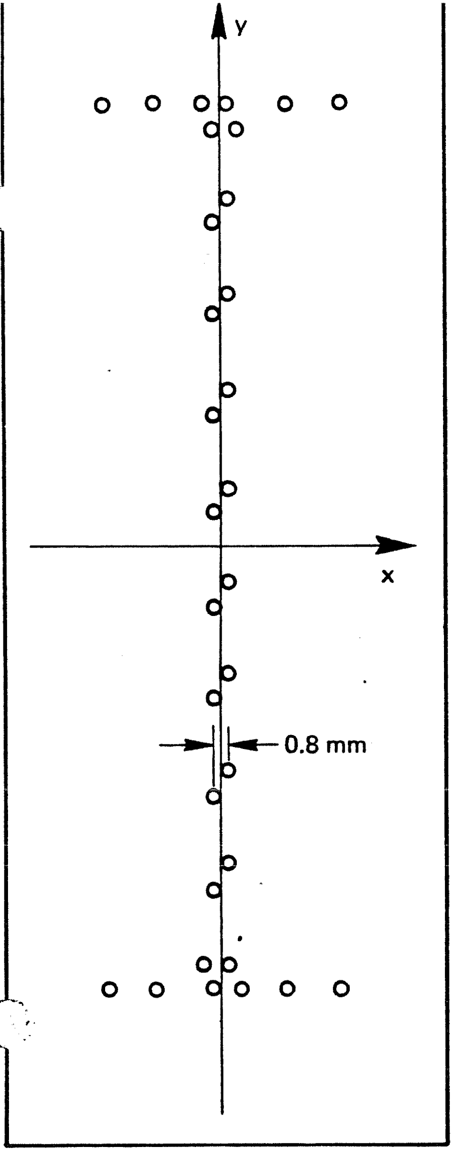

Fig. 2 Sensor Array Pattern

having an 18 inch (457 mm) stroke. The rotary table is driven by an electric stepping motor. For the Mill-Drill table, movement in the X- and Y- directions are independently controlled by hydraulic cylinders, each having a stroke of 12 inches (305 mm).

A PDP 11/40 minicomputer provides signals to the servovalves that control the actuators. The digital signals are first converted to analog form and then amplified to the appropriate levels. The stepping motor is controlled by the computer via a digital multiplexer, and speed regulation from 10 to 320 steps/sec can be achieved in both forward and reverse directions. In the future, the minicompter shall be completely or partially replaced by powerful microcomputers.

Position sensors

automated cut-off machine must be able to locate and orient the workpiece, i.e., the steel castings, repeatedly in specified positions since the REPEAT motions of the machine are identical to the motions made during the TEACH mode.

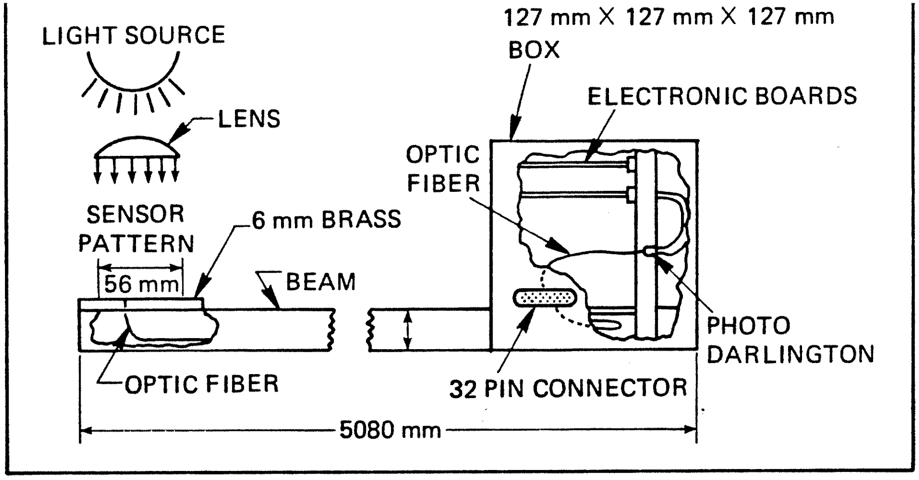

Fig. 3 Sensor Layout

The machine movements are measured using helical potentiometers. For accurate position measurement of the workpieces, optical sensors have been developed.[2] An optical sensor consists of a light source which emits a parallel beam, an array of photo-electric elements, and a visual display of the signals generated by these elements. The array configuration is flexible, and a typical design is given Fig. 2. The sensor accuracy is determined by the size and spacing of the elements in the array; dense spacing is achieved with the aid of fibre optics. Fig. 3 shows the arrangement of connection between 30 mil optic fibres and photo sensors. The signal is represented by a 'one' or a 'zero' in the computer depending on whether the detector receives light or not. The visual display consists of an array of lights which are in the same shape as the sensor element array. The machine operator can use the visual display to align the first workpiece when "teaching" the machine how to cut a workpiece of a particular shape; later, the display can be used to insure proper functioning of the machine.

The machine can be operated either from the computer console or by using manual devices. The X-and Y-axes of the Mill-Drill Table and the position of the rotating table can be controlled by a joystick in the manual and teaching modes. The operating states of the machine – automatic, manual and teaching, are displayed by light signals.

Control strategy and software

The control strategy is basically proportional position feedback, and makes use of stored data and instructions. To operate the machine repeatedly for castings of identical pattern, a human operator initially uses manual control on one typical casting. This is the Teach mode when the computer memorizes the machine movements to copy them in the subsequent REPEAT modes. Before initiating a cut-off operation, alignment of the workpiece is verified by the computer; any positional error is automatically sensed and corrected.

The software is implemented on a PDP 11/40 minicomputer with A/D and D/A conversion capabilities. The algorithm is designed in several modules to facilitate hardware realisation and to provide flexibility. The modules are programmed in standard FORTRAN and make use of the I/O routines written in the MACRO-11 assembler language. Fig. 4 illustrates the modular structure of the control routines. The main program acts as a command interpreter to call the following four modules as instructed by the operator:

1. Calibration Module – initially calibrates the position sensor and updates the gain settings for the position controllers.
2. Move Module – moves any of the four axes of the machine to a desired position on command from the computer console.
3. Teach Module – instructs the machine how to finish a casting using a new pattern by reading the position sensor signals and storing the information in data files.
4. Table and saw control Module – implements the feedback control strategies for all four axes of the machine.

Two basic data files are used by the modules:

1. Calibration Data File – contains the data for program initialisation. Its contents can be updated by the Calibration Module.
2. Pattern Description Data File – contains all the pattern descriptions for which an automatic cut-off cycle is available.

Clamping fixture

A fixture is used to position and clamp a casting for riser and runner removal. It should be capable of firmly and accurately positioning various types of castings, and the set-up time should be small.

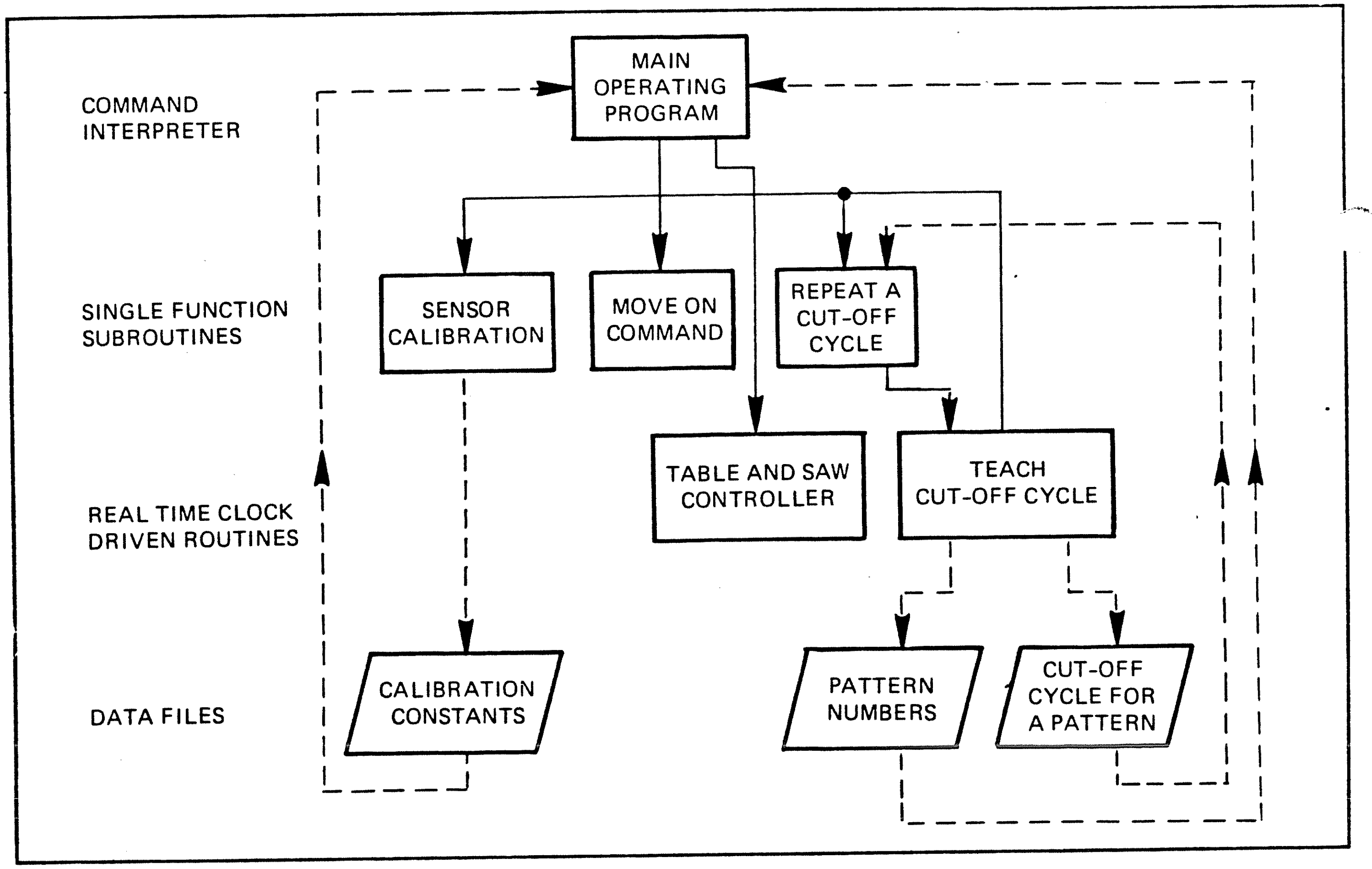

Fig. 4 Hierarchy of Program Software

The fixture, designed for the machine, consists of two V-blocks, a sprue cup holder and a clamping mechanism as shown schematically in Fig. 5. The V-blocks are accurately machined to proper angle so that the runner extensions make a good fit. The sprue cup holder is designed to grip the gate in such a way that it supports no weight.

Cutting devices

Commonly used devices for cutting steel castings are abrasive cut-off wheels, mechanical saws, and oxygen-fuel flame[1,3,4]; other techniques include laser cutters, plasma arc cutters, etc. Cutting devices are selected on the basis of thickness, shape and material of the workpieces to achieve the best trade-off in terms of initial equipment cost, consumable materials, cutting speed, and edge quality. Abrasive cut-off wheels are generally suitable for the castings that require straight cuts and thicknesses less than 2½ inches (640 mm). For thicker materials and curved cuts, oxygen-fuel cutters prove to be a better choice.

The performance of the proof-of-concept machine was demonstrated in a local foundry. Time study analyses were carried out to evaluate the effectiveness of automation with respect to existing manual operations for a sample of castings having a fixed pattern. Time savings were estimated to be approximately 20 percent. On an industrial basis, this is a conservative estimate because much improvement can be made in utilisation of this automated machine. The proof-of-the concept machine is now being modified to adapt abrasive cut-off wheels in place of circular saw blades.

Conclusions

A proof-of-concept machine has been designed, built and operated for remo of excess metal from steel castings. T machine is computer-controlled and can operate on TEACH and REPEAT modes. The use of the machine is technically feasible and a time-study analysis shows approximately 20 percent savings in cut-off time when compared to the existing manual operations.

With rapid progress in computer technology, automated cut-off machines are likely to be economically attractive for individual steel foundries. The TEACH and REPEAT automation has a potential for application in other manufacturing areas of steel foundries, sandslinger operations for example.

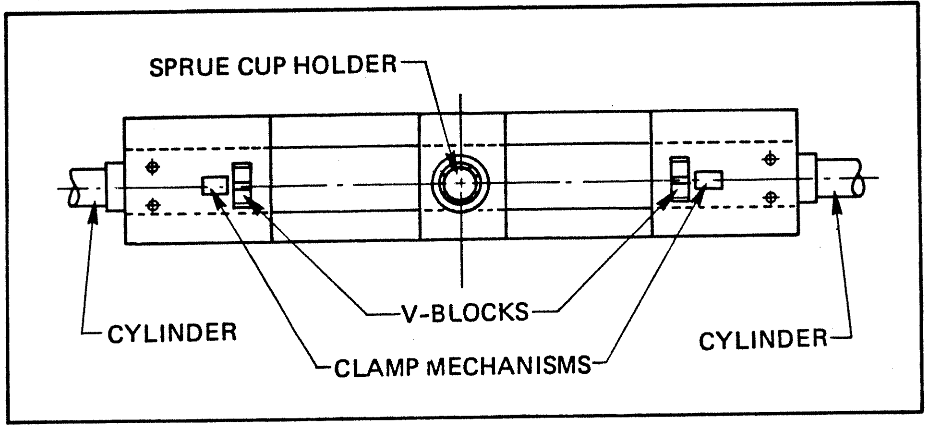

Fig. 5 Schematic of Clamp Fixture

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