

BENCH-TOP PRECISION GLASS MOLDING MACHINE

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INTRODUCTION

Extensive growth of opto-electronic technologies has created a demand for high quality lenses and has driven the industry toward a less expensive process for manufacturing of aspheric glass lenses called Precision Glass Molding (PGM). Based on the current understanding of thermal and mechanical response of glass at elevated temperatures, there is a need for a new type of machine which will allow the user to control specific process parameters. This paper discusses the use of such a tool, in support of material optimization for the PGM process.

Moore Nanotechnology Systems LLC. [1] and Toshiba Machine CO. [2] are two suppliers for glass molding machines in the US and both have designed their machines to be compatible with medium to large volume production of optics. Scientific research has a need for a smaller, bench-top sized version of these machines with flexibility in machine design optical component geometries and process parameters. The GP-5000HT precision glass molding machine from Dyna Technologies Incorporated (DTI) [3] was designed for this purpose. The machine has functionality comparable to commercially available products and also the flexibility for laboratory testing, research and prototyping of lens design.

The main objective of this study is to define the machine's functionality and measure the accuracy of the new design's control over thickness of pressed or molded lenses, an attribute (commonly described as center thickness, CT) which is critical in lens manufacturing. To this end, repeatability tests were conducted using two polished planar

Tungsten Carbide (WC) molds and Ohara L-BAL35 as the glass sample.

MACHINE FUNCTIONALITY

The GP-5000HT has a frame to house the heating system, mechanical system, and instrumentation. The frame is composed of two rectangular plates and four posts. The four posts close the structural loop of the machine by passing through the corners of the lower plate and connecting to the corners of the upper plate. The components of the frame and other mechanical parts of the machine can be found in Figure 1. Of all the machine systems described in this study, the only system attached to the frame of the machine is the mechanical system.

Mechanical Systems

The mechanical system is composed of an electric actuator and two pneumatic cylinders attached to the upper frame plate. The pneumatic cylinders are used to raise and lower the upper molding chamber. The upper portion of the molding chamber is connected to the ends of the pneumatic cylinders and the lower portion attached to the lower frame plate. This allows the lower portion to slide in and out from under the upper molding chamber. This sliding movement allows the user to easily insert or remove a molding sample. When the lower molding chamber is under the upper molding chamber, and when the chamber is closed the electric actuator can be operated.

The electric actuator provides the movement along the axis of the molds and the force needed for molding the glass. The actuator is attached to the upper frame plate and is connected in series with the load cell, post, and upper mold, respectively. The lower mold

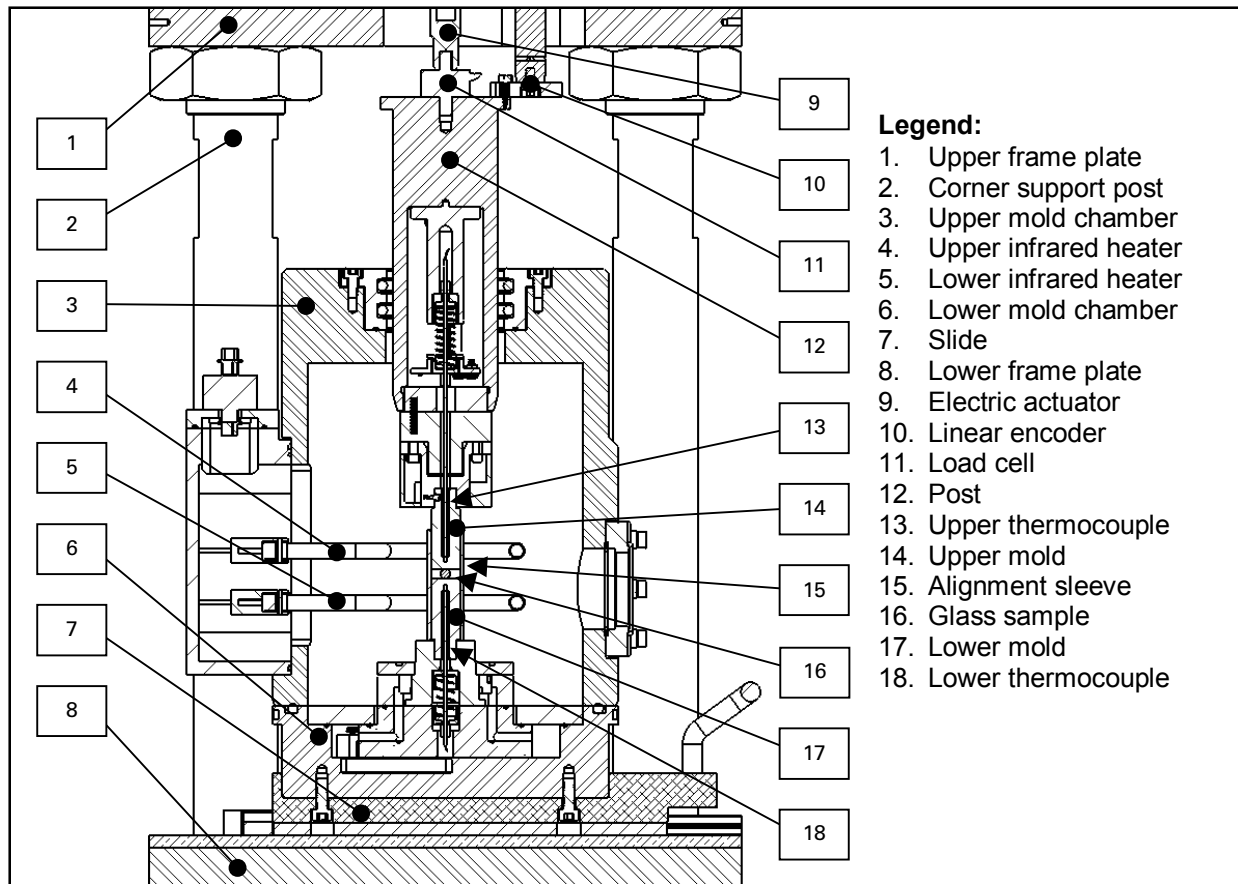


FIGURE 1. Above is a cross-section of the GP-5000HT revealing its critical components. The pneumatic air cylinders that lift the upper mold chamber along with the control boxes, which contain the electrical equipment for operating the GP-5000HT, have been excluded.

remains stationary throughout the molding process, and it is connected to the lower molding chamber. A sleeve around the lower mold is utilized to align the upper and lower molds which are made of WC. The WC is used because of its robust mechanical and thermal properties at higher temperatures[5].

Heating System

The heating system uses two omega-shaped infrared (IR) lamps. These allow the press to achieve temperatures up to 800 °C. The IR heaters are attached to the upper bell housing and are positioned so that each heats the molding sleeve equally. Power to the heaters is controlled by a proportional, integral and derivative (PID) heater controller. Heat from the sleeve is transferred to the molds through conduction. The glass sample is heated by conduction from the molds. The heating system also has the capability to heat and cool at specific rates within the limitations of the maximum heating rate and the maximum cooling

rate. Inert gas, typically nitrogen, is used for cooling cycles.

Instrumentation

The instruments used for assessing the press' performance are composed of sensors and other measurement devices. The sensors act as safety features, preventing any damage to the heating system, mechanical system, or the user of the press.

The measurement devices include the thermocouples, pressure transducer, load cell, and linear encoder used to govern the molding process. There is a hole aligned axially with the molds that are used for inserting a thermocouple to measure temperature, located up to 1/4" away from the molding surfaces. The readings obtained from these thermocouples are used to represent the temperature of the glass sample. The pressure transducer measures the static pressure of one of the pneumatic lines coming into the molding chamber. The load cell is

aligned axially with the molds and it is connected in series to the actuator to instantaneously measure the force applied to the glass sample during molding.

Molding Cycle

The molding cycle is comprised of several stages: purging, heating, soaking, molding and cooling. The molding process is driven by the measurement devices. Before a cycle starts, the user programs the setpoints for a molding program. The setpoints are the triggers that cause the press to move to the next stage in the cycle. The user has two options for running a pressing cycle: Auto Mode runs through a full cycle when the start button is pressed; Manual Mode gives the user control over when the different stages begin.

The user first inserts a glass sample onto the bottom mold. The press is then evacuated using a vacuum pump and then backfilled with inert gas three times in order to prevent oxidation of the molds and other components in the molding chamber. Once purged, the actuator moves into the sleeve and makes contact with the glass sample with a specified force. The heating stage begins, and the heaters heat at the user or controller defined ramp rate. After reaching temperature above the glass transition temperature of the sample, the press begins to soak for a specific amount of time. The soak allows the glass sample to equilibrate at a uniform temperature to be sure the glass has a uniform viscosity. The actuator then begins to press the glass into the shape of the molds. Once the specified position has been reached, cooling gas actively flows into the chamber. The press can be cooled at the maximum cooling rate or using up to three different cooling stages with control over the cooling rate and applied force. This cooling ramp control gives more control over the relaxation behavior of the glass. When the press reaches a safe user defined temperature, the mold chamber is raised and the molded glass sample is removed.

REPEATABILITY RESULTS

The goal of the repeatability measurements is to determine the ability of the press to produce similar results on a day to day basis, and also on a per cycle basis. Two data sets were collected to analyze the performance of the press. The target function for both of the data sets is thickness of the sample after it has been pressed.

Methodology

The samples used during the pressing cycles are square-cut plane parallel plate (PPP) windows of L-BAL35 glass. The glass used in the current study was L-BAL35 from Ohara, as there is sufficient published data on its optical and thermal properties. The glass's physical properties needed for PGM such as viscosity, glass transition temperature, viscoelastic response, and structural relaxation parameters are well known for L-BAL35 [4]. Dimensionally each PPP window square measures approximately 5 mm on a side, with a thickness of approximately 2 mm. While in AUTO mode, the press heats the sample to 587 °C and molds the sample with a force of 100 lbs. The sample is cooled in two stages, with a different rates of cooling.

The first data set includes only the data from the first cycle of the day. This data set is representative of the day to day variations. The second set of tests include data from all cycles, including the first-cycle-of-the-day data presented in the first data set. The second data set mimics a typical production cycle used in industry. Three sets of pressing cycles were taken on different days, with each day consisting of 10 consecutive cycles. The sample thickness was measured in 10 places to determine a mean value and standard deviation.

In the 10 consecutive cycles there are two distinct phases in the press' repeatability. The first phase, or the 'warm up' phase, includes the first 2-4 runs, where the press experiences thermal expansion between pressing cycles. The second phase, referred to as the 'steady state', includes all cycles after the warm up phase. The boundary line between the two phases is somewhat arbitrary, but is distinguished by a significant drop in the standard deviation of the thickness of the sample.

Results

The individual measurements of each sample show that they have a highly uniform thickness, varying only a few microns with a maximum standard deviation of 2 microns as listed in Table 1.

The change in thickness from one sample to the next can be attributed to the small scale thermal expansion and thermal conductivity of the system that continues even after the pressing

TABLE 1: lists the standard deviation and the total range of the thickness of an individual sample, the first molding cycle of the day, and the steady state.

	Individual Samples	First Cycle	Steady State
Standard Deviation (μm)	2	113	9
Total Range (μm)	6	246	19

cycle has finished. Table 1 also shows the total range and the standard deviation of the first cycle and of the steady state. There is a big difference in repeatability capabilities from the first cycle to the steady state; there is an order of magnitude drop of the standard deviation and the total range from the first cycle to the steady state cycles.

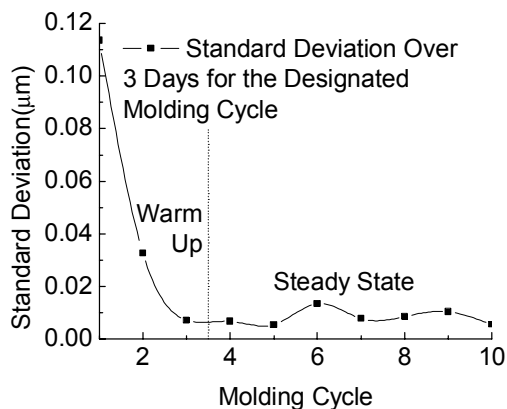


FIGURE 2: The standard deviations of the number cycle over multiple days in 10 consecutive pressing cycles.

Within the whole data set, the effect of thermal expansion on the target function can be analyzed. These results show several machine tool attributes that would be important to a manufacturer: the uniformity of the pressed part thicknesses, and how quickly (how many pressing cycles) before this uniformity can be obtained. As the press transitions from room temperature through the warm up phase, the average thickness of the resulting samples continually changes. However, once the press has reached its “steady state phase”, the thicknesses remain fairly constant. Comparing the standard deviation of each numbered cycle, from 1 to 10, over 3 consecutive days of cycles, a definite trend is evident, and is shown in Figure 2. As the number of cycles increases, the standard deviation of the sample thickness decreases.

CONCLUSIONS

A bench-top precision glass molding machine is a valuable tool for research in the demanding and growing opto-electronic industry and scientific field. It is a tool that can help bridge the difficult and important gap between scientific research and industrial manufacturing. The GP-5000HT is a glass molding machine with functionality similar to a full-production molding machine but is also versatile enough to be used for scientific research purposes.

Preliminary repeatability results utilizing pressed part thickness of plano-plano samples has shown an increase in thickness consistency from day to day as the number of molding cycles increases. There is still a large uncertainty to the first cycle results and that there is a definite “warm up” period, though industrial practitioners routinely run dry cycles over some defined period. The tolerances of the final thickness become much tighter after the system reaches thermal equilibrium, typically after 3 molding cycles. During the steady state cycles done over multiple days, the total range of thicknesses is 19 μm with a standard deviation of 9 μm .

Routine future tests (daily, weekly, etc.) with target boundaries and final piece tolerances can also be developed from this set to ensure the press is performing within acceptable limits of operation.

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