Automated Specimen Removal System

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Abstract
The minimization of the time required to conduct tensile testing of a high volume of material specimens results in cost and time savings for basic material manufacturers. Targeting this market, the Instron Corporation sells a fully automated tensile testing system, TestMaster™, that can test 20 specimens per hour. This system is comprised of an Instron 5580 series test frame, multiple specimen processing stations, and a multi-axial industrial robot to transport and dispose of specimens. To increase TestMaster™ throughput, an automated, closed loop controlled, electro-mechanical system to independently remove tested specimens and dispose of them into predefined locations was developed. Adherence to the design requirements set forth by the Instron Corporation prompted static and fatigue analysis, as well as a comprehensive strategy for the final integration of the removal system to the existing TestMaster™ system. This project culminated in the production of a functional prototype complete with the necessary subsystem control software and top level software drivers. The form, fit, and function of these items were tested at Instron’s research and development laboratory to verify all aspects of system compatibility. Subsequent testing proved that overall TestMaster™ throughput was increased by 13 percent.
The Need for Project

Increasing the throughput of automated tensile test systems reduces the time between material property inspection and market release.

Within the material manufacturing industry there exists a need to ensure the quality of a finished product. To guarantee uniformity between finished products, quality standards are established that define minimum material properties. To accurately assess the properties of a sizable lot of material, a statistically significant number of tensile tests are required. Therefore, to ensure the accuracy of all measurements, the entire testing process is automated. To accommodate this market, Instron manufactures an automated, high volume, tensile testing solution known as the TestMaster™ Automation System. An increase in the throughput of this system, or the number of specimens processed in a given hour, will reduce the time required for a given lot to pass inspection and be sold.

The Design Project Objectives and Requirements

The objective was to design and construct an automated specimen removal system that increases the throughput of the Instron TestMaster™ Automation System.

**Design Objectives**

The project objective was to design an automated specimen removal system that increased the throughput of the Instron TestMaster™ Automation System from the current processing time of 20 specimens per hour. A working prototype, satisfying all design requirements, was required at the conclusion of the project.

**Design Requirements**

The existing TestMaster™ Automation System utilizes a multi-axial industrial robot to process and remove the test specimens. The removal system was required to remove and dispose of tested specimens without the robot’s assistance within a 10 second time constraint.

The removal system needed to be compatible with the Instron 5580 series test frame and to mount without interfering with existing TestMaster™ accessories. The removal system was required to apply a 10 lbf load when dislodging the tested specimens from the Instron specimen grips. When applying this load, the removal system was not to deflect more than 3 mm.

To market this product competitively, the automated specimen removal system should have a manufacturing cost of $5,000.
**Design Concepts considered**

Conceptual designs were evaluated based upon TestMaster’s™ existing space constraints and potential to be scalable, sustainable, and cost effective.

**Design Concept 1 - Rotational Grabber Assembly**

The concept consisted of two identical assemblies, each mounted to the exterior of the specimen grips. A tested specimen could be disposed of in any radial position by designing the assembly to rotate freely around the circumference of the grips (Rep. 8.2). Upon investigation of this concept, modification of existing specimen grips was determined to be costly and a more scalable design was pursued.

**Design Concept 2 – Linear Actuated Swinging Arm**

The concept consisted of two similar assemblies, one mounted to the base plate and one to the crosshead. They were comprised of two main components: a rotating horizontal arm to acquire the tested specimen, and a linear actuator to translate the horizontal arm towards potential drop locations (Rep. 10). While meeting all functional requirements, this concept did not fit within the indicated space constraints. As a result, an effort was made to modify this concept towards a detailed design.

**Rotational Motion Alternatives**

Having decided on using the Linear Actuated Swinging Arm in a modified form, methods of attaining the desired motions were evaluated. For the rotational motion of the horizontal arm, two options were considered, a stepper motor and a pneumatic rotary actuator. The trade offs between these components were, increased functionality and versatility using a stepper motor, or limited functionality but reduced cost using a rotary actuator. It was resolved that increased functionality led to a more sustainable design and the additional cost of the stepper motor was deemed acceptable.

**Recommended Design Concept**

The design features a rotating arm assembly with position control. The specimen is removed through the proper coordination of the rotating arm, pneumatic specimen gripper, and pneumatic slide.

**Design Description**

*Mechanical*

The final design featured two removal devices, one mounted to the base plate and the other to the crosshead of the tensile test frame. Each of these devices were comprised of three assemblies: the adapter plate and linear base slide; motor and gearbox; and the arm and gripper. The adapter plate and base slide assembly allowed the removal system to be mounted to both the base plate and crosshead.
The base slide, which mounted to the adapter plate, was pneumatically driven and allowed the specimen to be transported in and out of the testing frame. The motor and gearbox assembly was mounted on the base slide and featured a stepper motor with an integrated controller and gearbox. The stepper motor and gearbox provided the rotational movement needed for articulation toward the specimen as well as the disposal locations. The arm assembly was rigidly coupled to the output shaft of the motor and gearbox. It featured a pneumatic gripper, which was able to acquire the tested specimen and release it in the proper disposal location. This was accomplished through the use of gripping fingers, which placed a resilient hold on the specimen when the pneumatic gripper was actuated.

**Pneumatic**

Four-way, two position solenoid valves were used to actuate the base slide and gripper. Each valve controlled a single pneumatic component and allowed for each component to be cycled independently. The pneumatic gripper could be either open or closed, and the base slide could be deployed in two positions located 100 mm apart.

**Control**

The integrated microcontroller of each motor was programmed to control its associated pneumatic base slide, gripper, and rotational position.

To simulate the TestMaster™ Automation System, a separate programmable microcontroller, referred to as the “TestMaster™ board”, was used. This microcontroller featured a sufficient number of digital I/O pins for communication and served the same function as TestMaster™.

The TestMaster™ board initiated each of the three subroutines of the removal process. These subroutines were specimen acquisition, removal and disposal, and homing of the removal device. The logic for each subroutine was programmed in the motor microcontroller. To initiate each subroutine, a unique I/O sequence was transmitted between the TestMaster™ board and the motor microcontroller. This communications protocol used three I/O pins for each motor.

The motor microcontroller used I/O sequencing to acknowledge
the completion of a subroutine or to convey a mechanical or hardware error. Each motor required two additional I/O pins to successfully communicate with the TestMaster™ board.

**Analytical Investigations**

The arm assembly was designed with considerations made to fatigue life, weight, cost, and aesthetic appeal. Through the use of finite element analysis software and a decision process, which included calculating the weight of components and associated costs, aluminum was chosen.

The pneumatic components and the motor and gearbox featured extended lives of at least five million cycles.

The valve flow coefficient for the air flow control valves was calculated based upon the volume of air in the system and the losses associated with the pneumatic components and tubing.

**Experimental Investigations**

The removal device was run with four thousand consecutive simulated removal cycles. This endurance test was used to verify the robustness of the logic in the microcontroller and the TestMaster™ board. The form, fit, and function of the removal device was tested at Intron’s research and development laboratory to verify all aspects of system compatibility.

**Advantages of the Recommended Concept**

The removal system completes a removal cycle in 8 seconds as opposed to the current TestMaster’s™ 33 seconds. This resulted in a 13 percent increase in overall throughput. The removal device could be used on various tensile test configurations through its modular design. The stepper motor allowed for the sorting of tested specimens into various drop locations. The removal device was also sustainable, as it could be used to transport specimens into the universal testing frame if a specimen cartridge were to be created.

**Financial Issues**

The initial budget of $5,000 was surpassed during the manufacturing phase of the project. Due to the level of repeatability required in a fully automated system, it was not possible to stay within the budget while accomplishing all of Intron's specific design requirements.
Specimen processing analysis for a 16 hour work day

Although the cost of the removal device was more than expected, Instron approved the budget. The production cost to Instron will be approximately $8000, allowing them to price the removal device competitively and generate profit. Additionally, the end user of the TestMaster™ Automation System will benefit from an increased level of throughput, shorter time to market for their materials, and experience a high return on their investment.

**Recommended Improvements**

Further endurance testing and manufacturing optimization could be performed to validate the system’s robustness and find potential lower cost alternatives to increase profit margin.

Given the project’s short duration it would have been beneficial to perform further endurance testing, adding to the cycles that were accomplished thus far. The endurance testing phase makes certain that the removal system’s hardware and software were designed properly and operate without error.

Manufacturing optimization should be considered if the automated specimen removal system were to become a standard Instron offering. Determining the best method to manufacture the machined components found in the removal system would reduce cost and material consumption. By evaluating component pricing from multiple suppliers and manufacturers, lower cost alternatives could be found to increase profit margin.