AUTOMATION OF SUPERPLASTIC FORMATION USING VIRTUAL INSTRUMENTATION

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Abstract:

Virtual Instrumentation is a software implementation of physical devices with advantages of easier control, process simulation, higher accuracy and digital storage. Superplastic offers low resistance to deformation hence it has many applications. In this project the process of Superplastic formation is completely automated using Virtual Instrumentation.

This project aims at controlling the applied pressure and maintaining a constant temperature so that the material can form at uniform wall thickness. The pressure regulator incorporates a stepper motor that can be controlled through a PC. The required pressure is varied in steps by actuating the stepper motor offering control similar to a proportional valve, at a lower cost. PID temperature controller maintains the required constant temperature by setting it in the controller. Based on bulge/deformation height pressure is varied so that occurrence of fracture in the material during the process can be avoided. Multi-turn potentiometer is used for this measurement with a small gear that is mounted along with the rack. Once the deformation in die reaches its maximum height, the pressure will be controlled automatically.

***Keywords**: Superplastic, Labview, automation, stepper motor, forming parameters, PID temperature controller, Multi-turn Potentiometer*

1 INTRODUCTION

Superplasticity is characterized by high temperature deformation giving neck free elongation of over 400% at low applied stress exhibited by metals and alloys with unique metallurgical characteristics. As high elongations are possible, complex contoured parts can be formed in a single press cycle often eliminating the need for multipart fabrications. This enables the designer to capture several detail parts into a one-piece complex, formed structure. Thus materials with superplastic properties can be used to form complex components in shapes that are very near the final dimension. Superplastic forming also enhances design freedom, minimizes the amount of scrap produced, and reduces the need for machining. In addition, it reduces the amount of material used, thereby lowering overall material costs[2].

Several components used in aircraft structures are presently being Superplastic, which is made out of titanium and aluminum alloys. Fuselage frames, nozzle for helicopters, turbine stator vanes, medical equipment panels and covers are examples of superplastic technique in applications.

Superplastic forming is a process for shaping superplastic materials, a unique class of crystalline materials that exhibit exceptionally high tensile ductility. Superplastic materials may be stretched in tension to elongations typically in excess of 200% and more commonly in the range of 400 to 2000%. There are rare reports of higher tensile elongations reaching as much as 8000%[4].

LabVIEW is the software used for the automation of Superplatic formation. LabVIEW (short for Laboratory Virtual Instrumentation Engineering Workbench) is a platform and development environment for a visual programming language from National Instruments. LabVIEW is commonly used for data acquisition, instrument control, and industrial automation on a variety of platforms including Microsoft Windows, various flavors of UNIX, Linux, and Mac OS[3].

One benefit of LabVIEW over other development environments is the extensive support for accessing instrumentation hardware. Drivers and abstraction layers for many different types of instruments and buses are included or are available for inclusion. These present themselves as graphical nodes. The abstraction layers offer standard software interfaces to communicate with hardware devices. Even people with limited coding experience can write programs and deploy test solutions in a reduced time frame because of the graphical programming approach.

The application areas for LabVIEW include measurements and instrumentation, circuit design, control design and simulation, signal and image processing, RF and communications, embedded systems[1].

In this paper the superplastic forming parameters and the automation of superplastic formation using these parameters are researched.

2 PROCEDURE

The following diagram depicts the block schematic of the automation process where the formation chamber, the feedback system and the control system is displayed. The temperature control inside the formation chamber is done by the PID temperature controller where the temperature for the metal is set before the initialization of the process.

A pressure regulating valve is used for the physical control of pressure. The valve regulates the quantity of air flow into the chamber, thereby limiting the pressure supplied.

The pressure control is realized by means of programs in Labview that monitor the input voltage from which the height of formed metal in the chamber is calculated. This data is used as a trigger for the stepper motor controller, which increases the pressure in steps till it reaches the threshold value determined from the manual formation process.

After the threshold height and pressure have been reached, the program automatically instructs the motor to turn the valve off so that the pressure is reduced, signaling the end of the formation process. The coupling between the stepper motor and the valve is accomplished by means of a coupler.

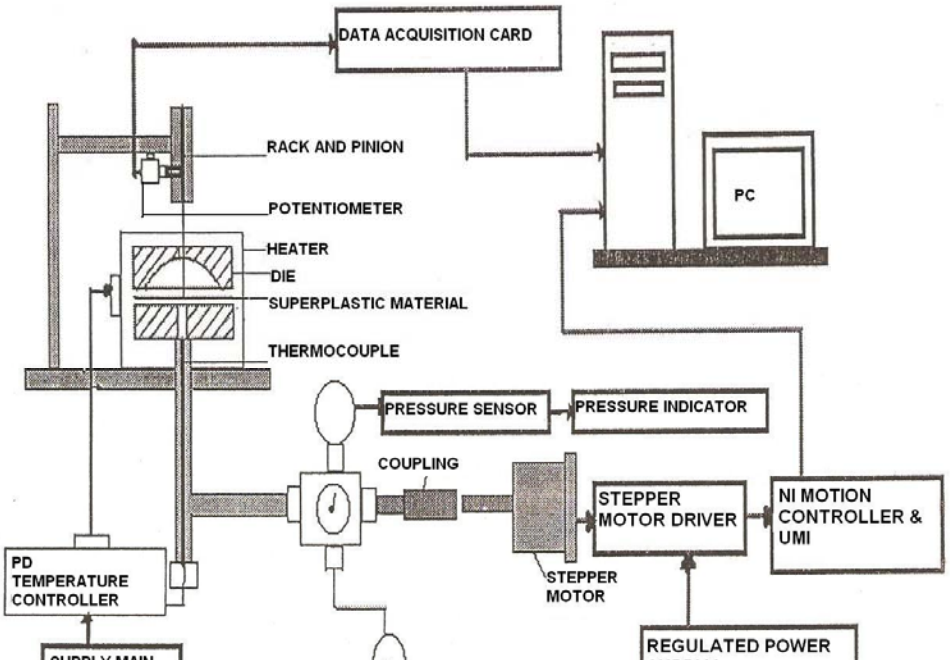


Figure 1 Overall Block Schematic

The entire paper is divided into three primary steps:

- Selection of material.
- Determination of forming parameters manually.
- Automated formation.

2.1 Selection of material

Superplastic material can be obtained from almost any material. The value of the forming parameters changes for different materials and for varying thickness.

Metals selected for this paper includes Aluminium, Copper and Zinc of varying thickness.

2.2 Determination of forming parameters manually.

The main parameters that dictate the formation of superplasticity are:

- Formation time
- Forming Temperature
- Forming Pressure
- Sheet thickness

Formation time can be defined as the time taken from the start of heating process in the die, to obtaining the die shaped Superplastic material.

Forming temperature is the temperature at which the material of a particular thickness exhibits superplasticity.

Forming pressure is the pressure, which should be applied to the metal sheet at the forming temperature to mould the sheet into the shape of the die.

Sheet thickness refers to the thickness of the sheet that is used for the formation of superplastic.

All the above listed parameters are closely inter-dependent and the variation of one can result in the variation of the others.

To determine these parameters, trial and error is the only technique available, as this information is still under research in many locations across the world. So manual implementation of Superplastic formation is resorted to, with the steps enumerated as follows:

1. A treated processed sheet of the chosen metal is cut into a small shape so that it fits into the space in the bottom half of the heater.
2. The thickness of the sheet is calculated using a screw gauge to provide accurate values.
3. An air compressor is used to feed the high pressure that causes the Superplastic moulding inside the heater.
4. The air compressor is connected through a pressure regulator to the heater chamber.
5. A PID Temperature controller is used to set the temperature at a constant value. The controller is connected to the heater apparatus to monitor and maintain a constant temperature.
6. A digital pressure indicator is connected from the pressure regulator, to indicate the pressure inside the heater chamber.
7. Rack and pinion setup is mounted on a stand, and the gear is mounted on the shaft of the potentiometer.
8. A 5V DC supply is given to the potentiometer, and the potentiometer is set at one end before mounting.
9. NI USB-6008 (Data acquisition device) is configured in NI MAX (measurement and automation explorer).
10. The rack and pinion arrangement is calibrated to obtain the height to voltage change ratio. This is calculated as follows:

Voltage/rotation: 0.5V
No of teeth: 48
Voltage/teeth= 0.5/48=0.01042V
7.6cm=1 rotation of gear
7.6/48=length per teeth
=1.583mm
Voltage/mm=0.00658V/mm
Height per unit voltage = 152.2mm

11. A virtual instrument is created in Labview 8.0 using DAQ Xpress to measure the input voltage from one analog input port of the NI USB-6008.
12. The calibrated ratio is used to evolve a logic that will convert the voltage change to deformation height. The height is compared with threshold deformation height to cutoff pressure by displaying a warning message.
13. In this manner, one module of the program, namely Deformation height calculation module is completed.
14. The air compressor is switched on and the pressure in the compressor is increased to 60 bars.
15. The heating coils are wound around the chamber and fastened using screws. The potentiometer to check the temperature inside the chamber is inserted into its slot on the top of the heating chamber.
16. Since the metal we used was aluminium, the temperature is set at 300C, just below half the melting point of aluminium[6].
17. The sensing rod of the rack and pinion arrangement is inserted into its slot on the top of the chamber.
18. The potentiometer is fixed on the stand and is connected to the Data acquisition device NI USB-6008.
19. After the temperature reaches the peak temperature of the respective metal, the pressure is increased in equal steps at equal intervals of time.
20. The rise in the height of the sample is continuously monitored on the PC, using the data acquired from the Rack and Pinion setup, through the DAQ.
21. The initial limiting formation height is set equal to the height of the die, though in reality, this height cannot be reached.
22. For determining the formation height, a few samples have to be fractured, as part of the trial and error method.
23. For each different thickness of sheet and pressure values, the formation time and height are noted.

2.3 Automated formation

The manual process of Superplastic formation as discussed previously is actually partly automated, in the sense that the height of the sample is automatically detected and fed into the PC. In order to fully automate the system, now, the only step that needs to be added is that the pressure supplied to the chamber needs to be controlled automatically by the computer, based on the inputs of formation height, time and pressure, by comparison with the limiting height, and calculated in the previous step by trial and error.

For this a pressure regulator, which is coupled to a stepper motor is used, which in turn is controlled by the computer, to open or close the regulator and accordingly increase or decrease the pressure in the chamber. When the height detection module finds that the height of the sample is approaching fracture point, it automatically instructs the regulator to reduce the pressure, in order to prevent fracture of the material.

It is seen that in the height detection sub-module the limiting formation height is given as an input, this input is compared with the detected height and comparison result is used as a trigger to the pressure control module that instructs the stepper motor to control the valve.

The interface between the computer and the sensing Potentiometer setup is done through a Data Acquisition Card NI USB 6008.

The Stepper motor control is executed through a motion controller NI 7340 to a Universal Motion Interface (NI- UMI 7764) which is connected to the third party driver unit that is connected to the stepper motor.

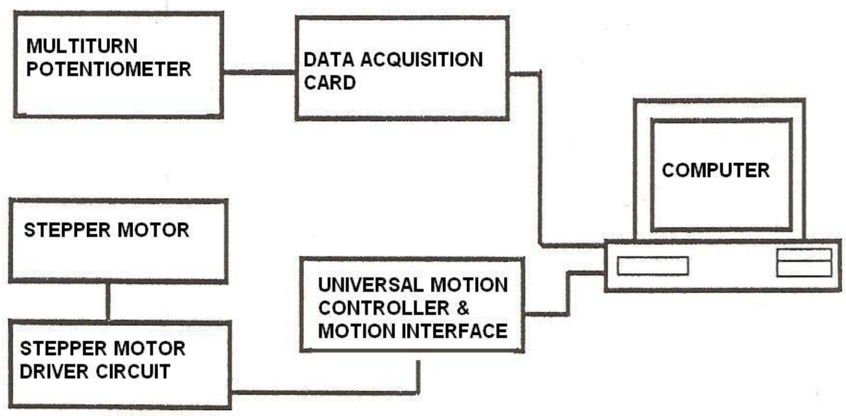


Figure 2 Block diagram of the Stepper motor control

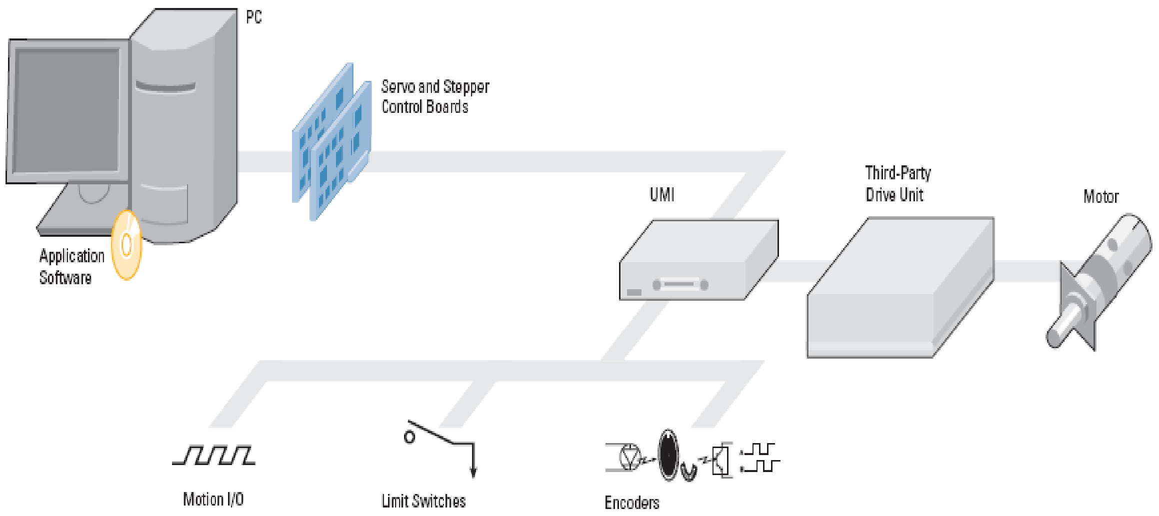


Figure 3 Block diagram for the configuration of National instruments UMI and Motion controller.

The above diagrams give an insight into the control system and its functioning. The Figure 2 shows the block schematic of the feedback and the control mechanism. The connection between the computer and the stepper motor as defined by National Instruments has been depicted in the block schematic in Figure 3.

The Motion Controller NI-7340 is a combination servo and stepper motor controller for PXI, Compact PCI, and PCI bus computers. The 7340 provides fully programmable motion control for up to four independent or coordinated axes of motion, with dedicated motion I/O for limit and home switches and additional I/O for general-purpose functions.

The 7340 can be used to perform arbitrary and complex motion trajectories using stepper motors or servo devices. Stepper axes can operate in open or closed-loop mode. In closed-loop mode, they use quadrature encoders or analog inputs for position and velocity feedback (closed-loop only), and provide step/direction or clockwise (CW) /counter-clockwise (CCW) digital command outputs. All stepper axes support full, half, and microstepping applications.

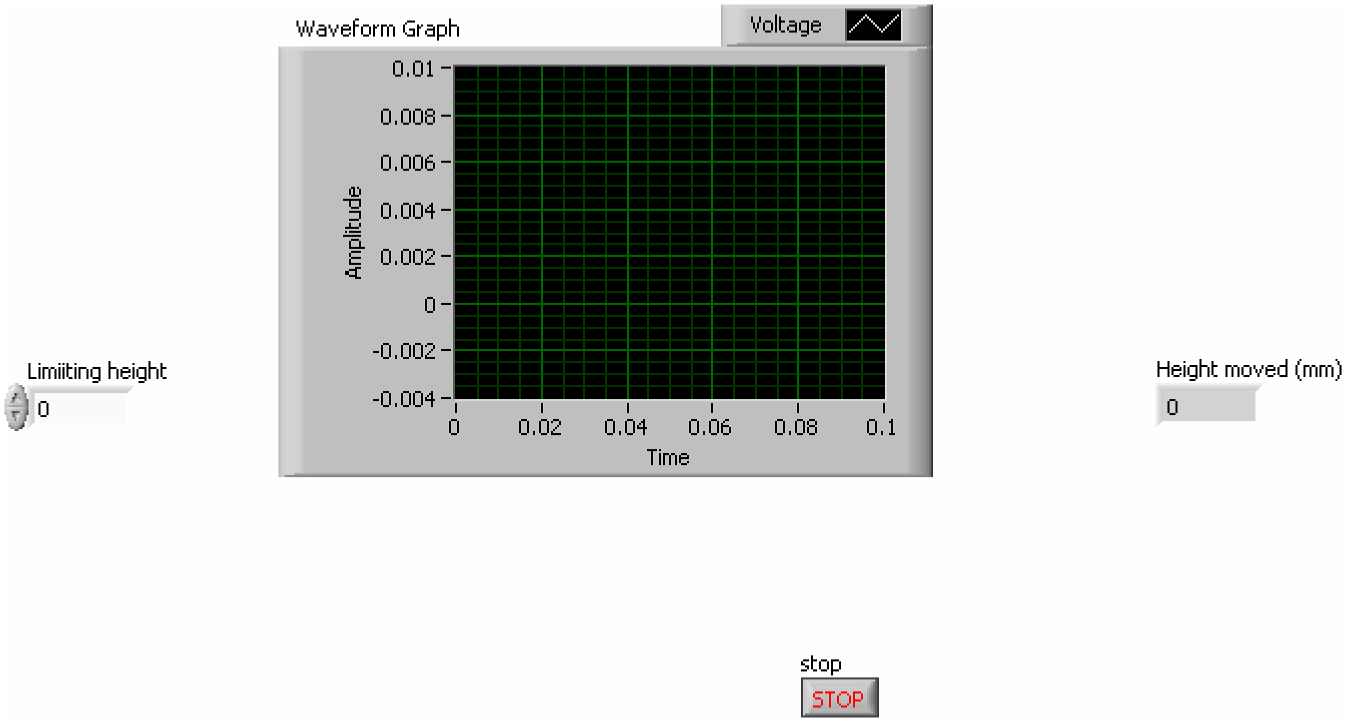
A UMI accessory simplifies field wiring with separate encoder, limit switch, and amplifier/driver terminal blocks per axis. All terminal blocks are industry standard and do not require any special tools for wire installation. The UMI accessory connects to the motion controller via a single interface cable. The UMI accessory has a host bus monitor power interlock that automatically disables the amplifiers if the host computer is shut down or the interface cable is disconnected.

The National Instruments USB-6008 and USB-6009 multifunction data acquisition (DAQ) modules provide reliable data acquisition at a low price. With plug-and-play USB connectivity, these modules are simple enough for quick measurements but versatile enough for more complex measurement applications[5].

The rack and pinion assembly is used for the measurement of bulge height or the deformation height of the material inside the die. The gear or pinion is fabricated using steel. The pinion being used has 48 teeth. Internal diameter of the pinion is 0.65cm and the thickness is 4mm.

The rack is manufactured using Aluminum. The thickness of the rack is 0.15cm and is 30cm in length. The teeth in the rack are designed in such a way that the mesh between the gear and the rack is very accurate and are capable of obtaining a very small variation in the displacement of the metal inside the die.

A 12V, 1amp/phase stepper motor is coupled to the pressure regulator knob. The stepper motor performs the opening and closing of the pressure regulator knob to vary pressure inside the heater. The commands to the stepper motor regarding the direction and number of steps to move are provided by the LabVIEW program through the stepper motor driver circuit.



Limiiting height 0

Height moved (mm) 0

Figure 4 Front Panel of Height Calculation Program

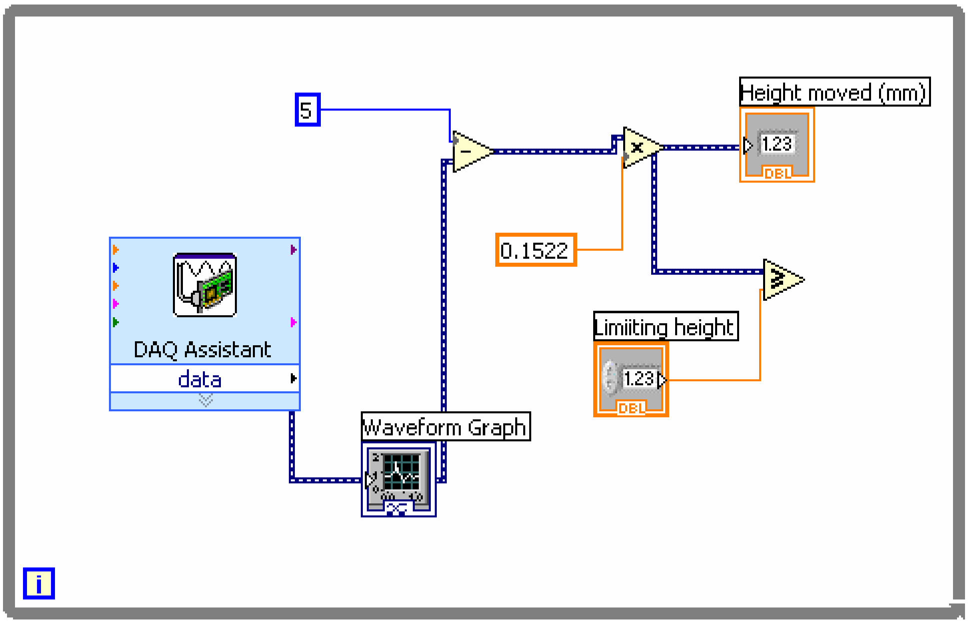
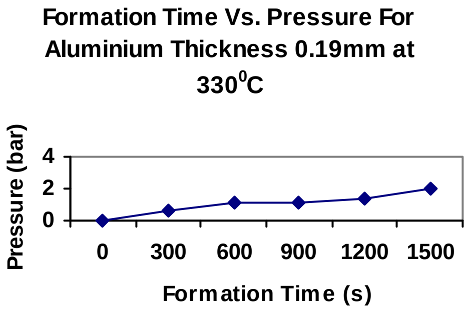


Figure 5 Block Diagram of Height Calculation Program

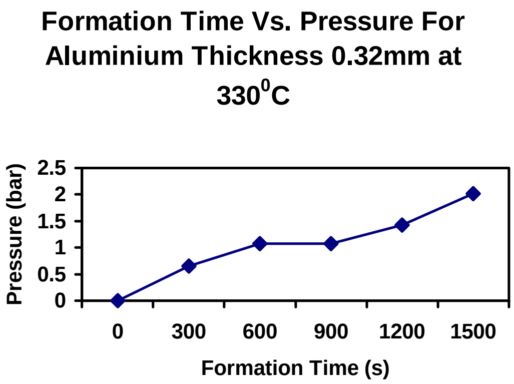
The above diagrams depict the front panel and back panel of the height calculation program in Labview. This program uses the calibration which is explained in the procedure. The DAQ assistant senses the voltage received from the USB-6008 DAQ device, through 1 channel which is then converted into height factor by using the calibration multiplication factor.

3 OBSERVATIONS

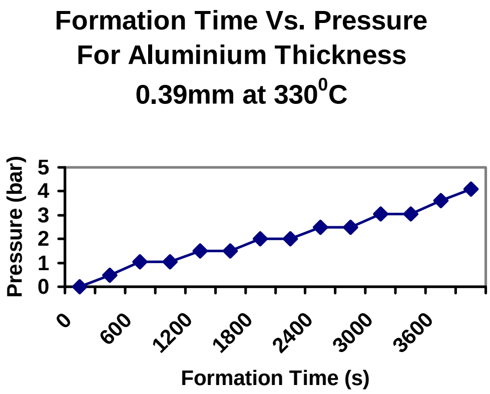
Formation processes for various metal sheets of different thicknesses were undertaken and their forming parameters were determined. The results for forming time and the applied pressure for both fractured and non-fractured samples are tabulated and the corresponding graphs are plotted. The following graphs and tables depict the results of the implementation.



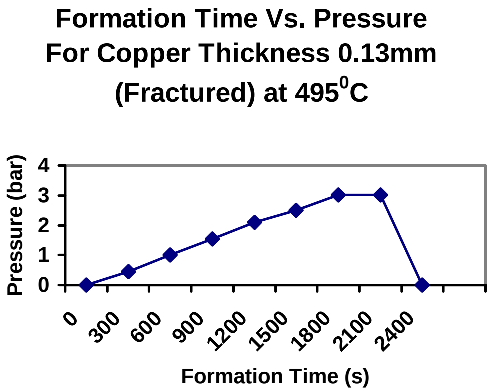
Graph 1



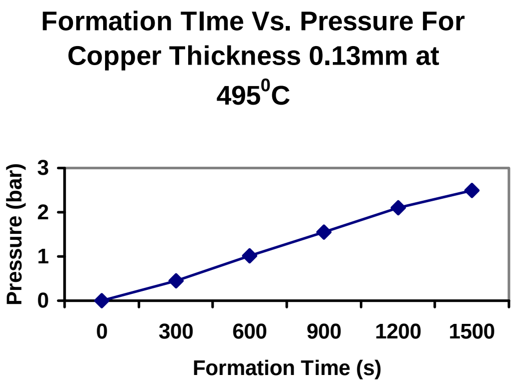
Graph 2



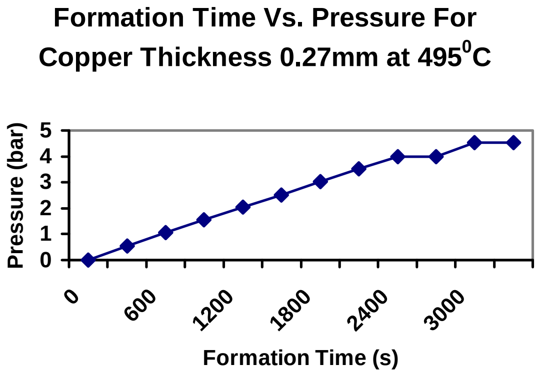
Graph 3



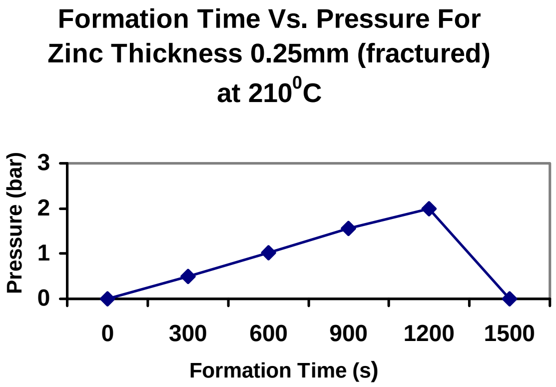
Graph 4


Formation TIme Vs. Pressure For Copper Thickness 0.13mm at 495^{0}C

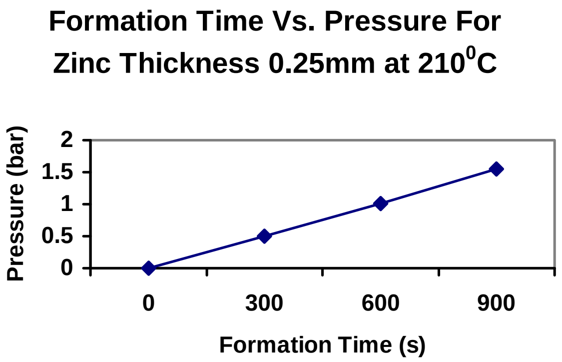
Graph 5


Formation Time Vs. Pressure For Copper Thickness 0.27mm at 495^{0}C

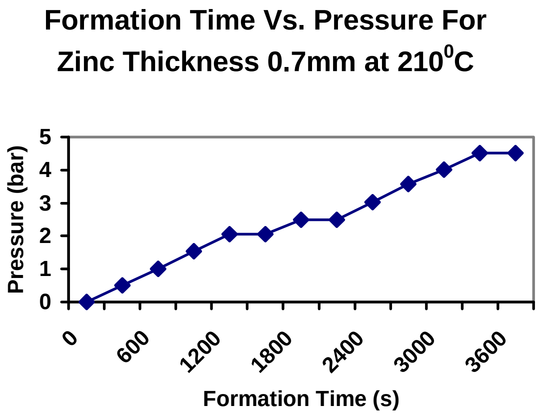
Graph 6


Formation Time Vs. Pressure For Zinc Thickness 0.25mm (fractured) at 210^{0}C

Graph 7



Graph 8



Graph 9

Table for Formation time vs Pressure for Aluminium of 0.19mm thickness

.No	Formation Time	Pressure
1	0	0
2	300	0.65
3	600	1.07
4	900	1.07
5	1200	1.43
6	1500	2.02

Table for Formation time vs Pressure for Aluminium of 0.32mm thickness

.No	Formation Time	Pressure
1	0	0
2	300	0.65
3	600	1.07
4	900	1.07
5	1200	1.43
6	1500	2.02

Table for Formation time vs Pressure for Aluminium of 0.39mm thickness

S.No	Formation Time	Pressure
1	0	0
2	300	0.48
3	600	1.05

ISSN 1512-1232

4	900	1.05
5	1200	1.5
6	1500	1.5
7	1800	2
8	2100	2
9	2400	2.48
10	2700	2.48
11	3000	3.04
12	3300	3.04
13	3600	3.6
14	3900	4.1

Table for Formation time vs Pressure for Copper of 0.13mm thickness (fractured)

S.No	Formation Time	Pressure
1	0	0
2	300	0.45
3	600	1.01
4	900	1.55
5	1200	2.1
6	1500	2.5
7	1800	3.01
8	2100	3.01
9	2400	0

Table for Formation time vs Pressure for Copper of 0.13mm thickness

S.No.	Formation Time	Pressure
1	0	0
2	300	0.45
3	600	1.01
4	900	1.55
5	1200	2.1
6	1500	2.5

Table for Formation time vs Pressure of Zinc for 0.25mm thickness

S.No.	Formation Time	Pressure
1	0	0
2	300	0.5
3	600	1.01
4	900	1.55

Table for Formation time vs Pressure of Copper for 0.27mm thickness

S.No.	Formation Time	Pressure
1	0	0
2	300	0.55
3	600	1.05
4	900	1.55

5	1200	2.05
6	1500	2.51
7	1800	3.03
8	2100	3.51
9	2400	4
10	2700	4
11	3000	4.54
12	3300	4.54

Table for Formation time vs Pressure of Zinc for 0.25mm thickness (fractured)

S.No.	Formation Time	Pressure
1	0	0
2	300	0.5
3	600	1.02
4	900	1.55
5	1200	2
6	1500	0

Table for Formation time vs Pressure of Zinc for 0.7mm thickness

S.No	Formation Time	Pressure
1	0	0
2	300	0.5
3	600	1.0
4	900	1.53
5	1200	2.05
6	1500	2.05
7	1800	2.49
8	2100	2.49
9	2400	3.02
10	2700	3.57
11	3000	4.02
12	3300	4.51
13	3600	4.51

4 CONCLUSION

The automation of the super plastic formation process with various sensors facilitates the automatic control of pressure for the given material. This type of system avoids human intervention, reduces the fracture probability and maintains the required pressure for deformation during the forming process.

This research project involved three basic steps:

1. Selection of material
2. Determination of forming parameters manually.
3. Automated formation.

Aluminum, copper and zinc sheets of varying thickness were used for the formation of superplastic material. The forming parameters like forming pressure, forming temperature and forming time were successfully determined for all the above said metals.

The bulge height determination of the material inside the die was completely automated using the LABVIEW software. This program feeds instantaneous height information of the forming material to the PC.

Based on the bulge height information of the sample the stepper motor has to be controlled automatically to open and close the valve of the pressure regulator.

Thus the automation of super plastic formation ensures the integrity of the component and the control system approach using LABVIEW improved the qualitative performance of the system.

[This research is being conducted with funding from the All India Council for Technical Education (AICTE) under the MODROBS scheme.]

5 FUTURE ENHANCEMENTS

Further enhancements of this research project include the formation of Superplastic using alloys of various metals like Lead and Tin in various ratios. Pre-treatment of the metals, to reduce their grain size will also be undertaken to improve the quality of the formed product.

6 HARDWARE SPECIFICATIONS

Multi-turn potentiometer:

Resistance Range: 100 Ohms to 10K Ohms.
Resistance Tolerance: + or – 5%.
Linearity Tolerance: + or – 0.25% independent.
Noise: 100 Ohms ENR.
Rotation: 3600 degrees, +10 degrees, -0 degrees.
Power Rating: 2W at +700C to 0W at 1250C
Insulation Resistance: 1000 Meg Ohm min, 500V DC.
Stop Strength (static): 5.4 Kgm-cm (75 oz in).
Rotation Life: 1,000,000 shaft revolutions.
Load Life: 900 hr

NI Motion Controller 7340:

Voltage range: 0 to 5 V
Input low voltage: 0.8 V
Input high voltage: 2 V
Number of inputs: 12 (3 per axis)

Analog outputs:
Number of outputs: 4-single ended
Output coupling: DC
Voltage range: ±10 V
Output current: ±5 mA
Resolution: 16 bits, no missing codes
Monotonic: Guaranteed
Analog reference output: 7.5 V (nominal) at 5 mA

Digital I/O:
Ports: 4, 8-bit ports
Line direction: Individual bit programmable

NI USB 6008 DAQ:

Analog Input:
Absolute accuracy, single-ended
Number of channels: 8 single-ended/4 differential
Type of ADC: Successive approximation
Input range, single-ended: ±10 V
Input range, differential: ±20, ±10, ±5, ±4, ±2.5, ±2, ±1.25, ±1 V
Maximum working voltage:±10 V

Air Compressor (Gajendra Compressors):

Motor speed: 750rpm
Motor power: 2HP
Peak pressure: 14kg/cm^2

Power Supply:

Voltage: 5V, 12V

Stepper Motor:

No. of Poles: 4
Voltage: 12V
Current: 1A/Phase

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Article received: 2009-06-29