CHAPTER 4

Experimentation

4.1 PLAN OF EXPERIMENTATION

The plan is to draw 2mm EDD steel at various thickness reductions for excessive plastic deformation at different temperatures. The experimental setup required for conducting experiments includes a power source (Hydraulic Power source) to apply punch force and blank holding force, heating systems for heating blank and die (two induction heaters), instrumentation to measure load and displacement of the punch (load cell and displacement encoder), data acquisition system , and temperature measuring device (infrared pyrometer)

The schematic diagram of total experimental set up is shown in Fig. 4.1

4.2 RAW MATERIAL

The chemical composition of EDD steel sheets used in the present investigations was analyzed by a spectrometer. These chemical composition results are shown in Table 4.1 and mechanical properties in Table 4.2.

Table 4.1. Chemical composition of EDD steel sheets (in weight percent).

Element	C	Si	Mn	S	P	Cr	Sn	Cu	Ni	Mo	Fe
Weight %	0.048	0.83	0.39	0.024	0.019	0.027	0.004	0.019	0.054	0.028	Rest

Table 4.2 Mechanical Properties of EDD steel at room temperature

UTS, (M Pa)	**YS, (M Pa)**	**STRAIN AT YS**	**ELG %**
337	202	0.0222	44

Size of the Raw material: 2mm thick with 58mm, 60mm, 62mm and 65 mm diameters cut down on CNC lathe by using a special fixture.

4.3 EQUIPMENT

The conducting experiments following equipment/instruments are used to study forming behavior of EDD steel at elevated temperature.

1. A double acting hydraulic press with temperature resistant punch, die and blank holder
2. A Heating System for Blank heating and die heating
3. Temperature measuring Pyrometer
4. Data acquisition System for Load and displacement
5. Universal testing machine with specimen heating facility
6. Scanning Electron Microscope
7. Metallurgical Microscope for observing microstructure
8. Micro Hardness tester
9. Pointed Anvil Micrometer

4.3.1 Double Acting Hydraulic Press

A double acting hydraulic press is used which is specially ordered to M/S Universal Hydraulics, Hyderabad with the given specification for the purpose of forming a deep drawing under various wall reductions to study flow forming behavior. The specifications given are as under.

Capacity of the Press	:200 kN
Electrical Motor HP	: 3.73 k W / 5 HP
Main Ram Bore Diameter (mm)	:140 mm
Main Ram rod Diameter (mm)	: 90 mm
Main Ram Stroke	: 500 mm
No of main cylinders	: 1 no
Blank holder ram Bore diameter	: 40 mm
Blank holder ram Rod diameter	: 25 mm
Blank Holder Ram Stroke	: 300 mm
No of Blank holder cylinders	: 2 nos
Pressing Speed	: 30~ 500 mm/min (Adjustable)
Max Operating Pressure	: 13720 kN/m^2
Open Day light gap	: 450mm
Closed Day light gap	:150 mm

4.3.2 Die, Blank Holder and Punch Design

Die, blank holder and punch in a typical deep drawing operation are designed in such a way that excessive stress concentration does not appear in any part of the drawn cup. So, (4-5) times t (where 't' is the sheet thickness) curvature is given over the punch corner and around (8-10) times t curvature is given over the die. Around 2% of the Y.S. pressure is applied on the blank holder to avoid wrinkling of sheet as compressive hoop stresses develop in the flange region of the cup. Also if the blank holding pressure is more, there will be fracture in the sheet just in the beginning of drawing. In conventional deep drawing, usually the clearance between punch and die is around 120% of the sheet thickness. It should be noted that smaller clearance produces ironing and larger clearances produces improper geometry of the drawn cup. In the present research there was a plan to decrease the clearance between punch and die to see the effete the percentage reduction and temperature on the flow properties of 2 mm EDD sheet. Three different dies are used to study the effect of "extent of deformation". Initially 40% reduction in the 2mm EDD sheet was provided (clearance between punch and die is 1.2mm). It was then increased to 25% reduction (clearance 1.5mm) and finally 10% reduction (clearance 1.8mm) over 2mm sheet thickness. The dimensions along with design of these dies are shown in Figs 4.2-4.4.

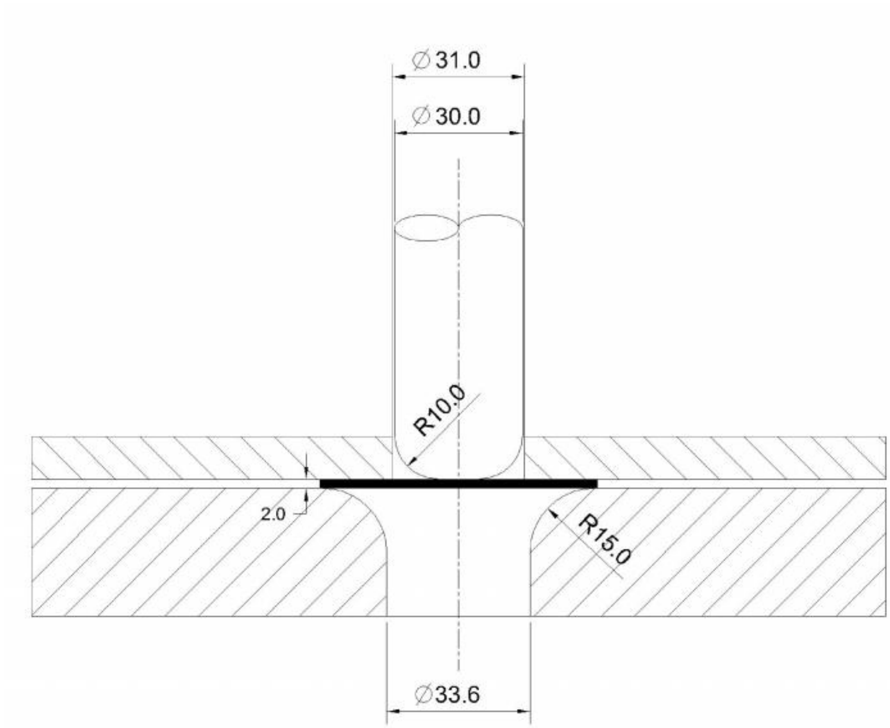

Fig.4.2 Tooling for 10% reduction in the thickness of 2 mm sheet.

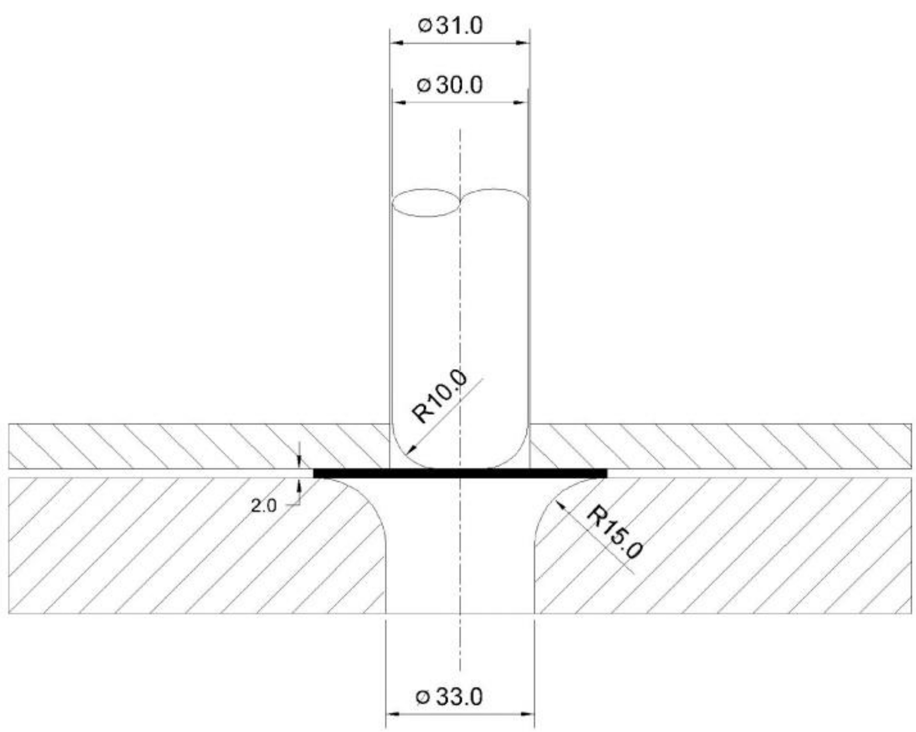

Fig. 4.3 Tooling for 25% reduction in the thickness of 2 mm sheet.

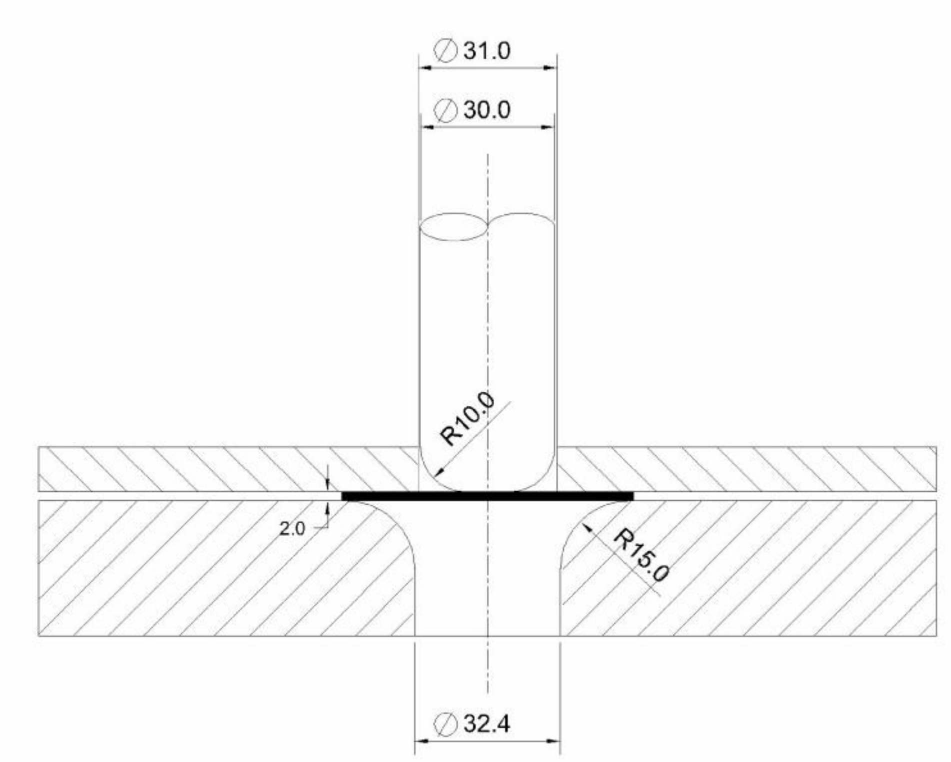

Fig.4.4 Tooling for 40% reduction in the thickness of 2 mm sheet.

The present study is to investigate the deformation of 2mm EDD sheet at elevated temperature and to minimize the changes in the design of dies to see the tools retain their strength. Inconel alloys are oxidation and corrosion resistant materials well suited for service in extreme environments. When heated, Inconel forms a thick, stable, passivating oxide layer protecting the surface from further attack. Inconel retains strength over a wide temperature range, attractive for high temperature applications where aluminum and steel would succumb to creep as a result of thermally-induced crystal vacancies So, for this purpose Inconel-600 material was chosen to make dies.

The properties of the Inconel 600 is given in the Table 4.3

Table 4.3. Chemical Composition of Inconel 600

Element	C	Si	Mn	Cr	Fe	Cu	Ni
Weight percent	0.15	0.5	1	14~17	6~10	0.5	72

The mean coefficient of thermal expansion of Inconel is 13.8 x 10^{-6} m/m-^{0} K and Modulus of Elasticity is 207 G Pa

4.3.3 MANUFACTURE OF THE PRESS

Every care has been taken for the robustness of the press fabrication of top and bottom platens. Four pillars are used to support Hydraulic cylinders smooth movement of blank holding plate. Alignment of the die and punch, pistons and cylinders of the hydraulic system are checked. Inconel die and punch are manufactured on CNC lathes and tested for geometrical features such as cylindricity, ovality, taper etc. The outer surface of the punch and inner surface of the die are finished by buffing process

4.3.4 TESTING OF THE PRESS:

For testing purpose initially the one set of die and punch is made out of die steel and several cups are drawn by changing the raw materials and the sizes. Aluminium and Low carbon steel blanks of various sizes and thicknesses are drawn. The leakages of hydraulic system and movements of the blank holder and punch are observed and found satisfactory. Also the equipment is checked for max traverse of the punch and blank holding plate. The total setup of the press is shown in the Fig 4.5. Fig 4.6 shows the Die punch and Blank holder made of Inconel

Fig. 4.5 Complete Experimental Test Rig.

Fig 4.6 Punch Die and Blank Holder Setup

4.4 HEATING SYSTEM

An induction furnace [Fig 4.7] is developed to heat the blank. In a simple transformer when the primary is connected to A.C. Mains, an alternating magnetic field is produced in the core and the voltage induced in the secondary winding is proportional to primary voltage and frequency. The energy transfer can also take place without the iron core.

In this configuration the secondary windings are replaced by a work piece to be heated, the latter can be regarded as a secondary winding with one short circuit turn. This at the same time is the basic arrangement at an induction heating installation, inductor becomes the primary and the work piece secondary, induction eddy currents are induced in the work piece and it gets heated.

An induction heating system consists of a source of alternating current (AC), an induction coil, and the work piece to be heated. The basic phenomena which underline induction heating are best understood with reference to the interaction between the coil and the work piece; the role of the power supply in this case is taken into account only in terms of the frequency and magnitude of the AC current which it supplies to the coil. By this means, the electrical and thermal effects which are induced in the work piece through its coupling with coil are deduced.

Induction heating relies on two mechanisms of energy dissipation for the purpose of heating. These are energy losses due to Joule heating and energy losses associated with magnetic hysteresis. The first of these is the sole mechanism of heat generation in nonmagnetic materials (e.g., aluminum, copper, austenitic stainless steels and carbon steels above the Curie, or magnetic transformation, temperature) and the primary mechanism in ferromagnetic materials (e.g., carbon steels below the

Curie temperature). A second less important means of heat generation by induction for the latter class of materials is hysteresis losses.

The developed induction heating system consists of a power source and tank circuit. The power source converts the power supply from S.E.B to medium frequency single phase output which is fed to a tank circuit. The tank circuit consists of a capacitor and work coil whose resonant frequency is tracked and determines the output frequency of the power sources so the maximum energy is transferred to the work pieces.

This system is designed to heat Iron maximum up to 700°C (slightly above the Curie point). Along with heating the blank, the lower die was also heated by providing another induction coil around it [fig 4.8]. It is done so that when the hot blank is kept over the dies, it should not develop a thermal shock. This die is heated to a predetermined temperature so that drawing process can be done at a particular temperature.

Fig. 4.7: Induction furnace used for heating the blank.

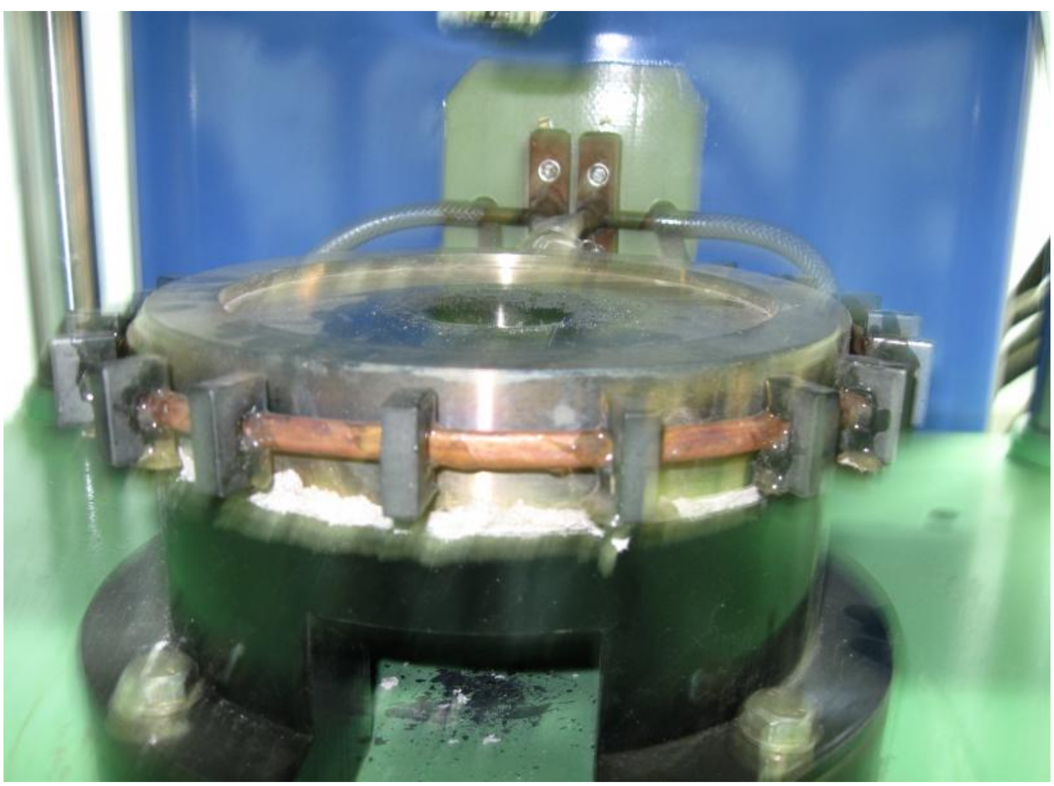

Fig. 4.8 Induction coil connected to the Inconel die for heating it up to 500^{0}C.

4.5 TEMPERATURE MEASUREMENT

Fig 4.9 is to explain how the measurement system of temperature does not make contact with the die and the blank

The non-contact temperature measurement (pyrometry) is an optical measurement based on the property of all materials to send out electromagnetic radiation (infrared radiation). The infrared thermometer (pyrometer) uses this radiation to determine the temperature. The pyrometer aims with the optics at a certain spot of the object and determines the temperature of this spot. Today typically spectral responses of pyrometers are in the near, middle and distant infrared.

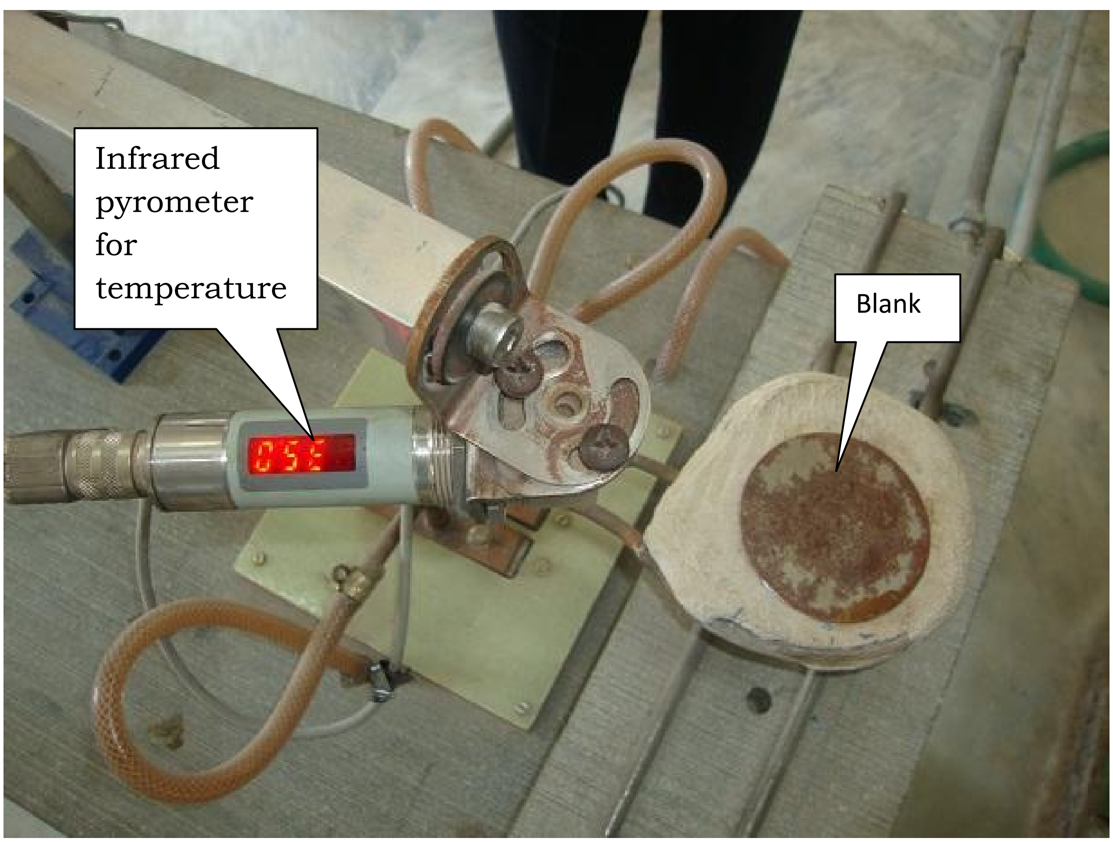

Fig 4.9. Blank Heating Arrangement with Temperature Measurement

The dimensions of the measured object determine the required spot size of the pyrometer. At least the spot size has to be in relation to the measured object to achieve a correct temperature measurement. The spot sizes are dependent on the type of pyrometer and measuring device, they can be calculated using the distance ratio or field of view (FOV). Where FOV is measuring distance / spot size (e.g. 240:1 means: in a distance of 1200 mm the spot size is 5 mm).

4.6 DATA ACQUISITION SYSTEM

Data acquisition system is provided to record the punch load and the displacement that can be directly loaded into the computer for further processing of the data.

4.6.1 Load Cell 200 kN

Load cell transducer converts the force into signal. The strain gauge measures the deformation because it changes the resistance of the wire. Finally the output of the transducer is plugged to calculate the force with algorithm. Such load cell is shown in fig.4.10 which is of 196kN /20tons capacity.

Fig 4.10 Load cell of the Data Acquisition System

4.6.2 Pressure Transducer

There are different types of pressure sensors. One is an absolute pressure sensor which measures absolute pressure using vacuum as a reference point. Another is a gage sensor which measures pressure with reference to the ambient atmospheric pressure. There are also differential pressure sensors which measure the pressure difference between two contacts. In this press, a pressure transducer is used to measure the blank holding pressure. Fig 4.11 shows the pressure transducer. Prior to pressure transducer a one way valve is connected by adjusting the pressure on the blank holder that can vary. It is understood that at high temperatures lower blank holding pressure will be required to draw the material

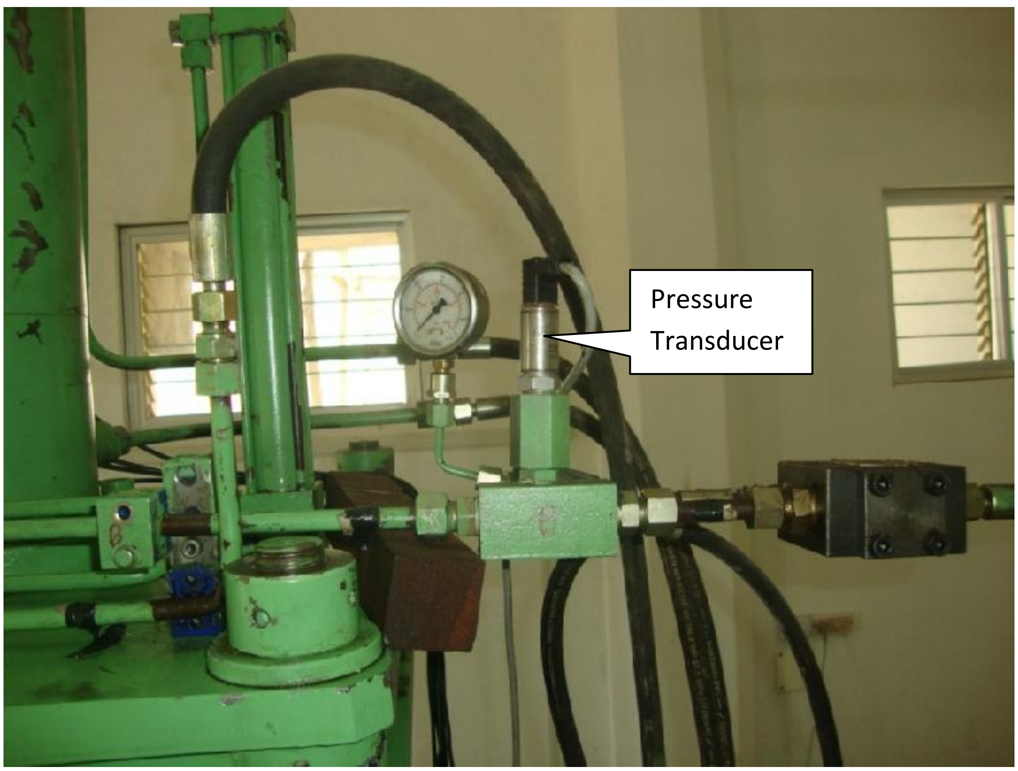

Fig 4.11. Pressure Transducer to measure Blank holding Pressure

4.6.3 Displacement Encoder

The displacement encoders convert the linear movement of the punch into electrical signals. This system is incorporated only to the data and about the digital data of the punch. Fig 4.12 explains this method very clearly. Rotary encoder in the system is connected through a mechanism with the punch.

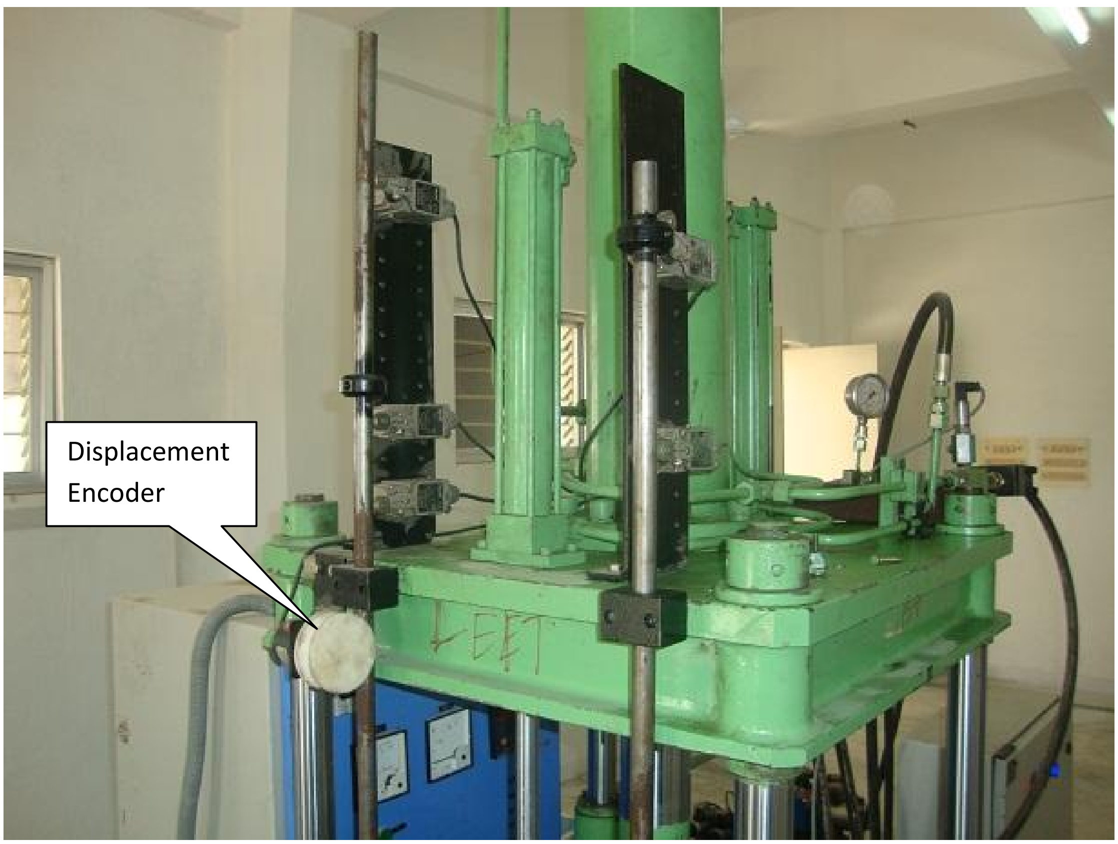

Fig 4.12. Encoder for Punch movement data acquisition

4.6.4 Interface Unit

The output signals from load cell and Punch displacement encoder-are connected to interface unit [Fig 4.13]. This, in turn, connects to a computer. The use of comprehensive range of functions in the intuitive, user-friendly software to monitor, record and analyses the experiment data. This unit transforms raw data instantly which easily exports or creates graphs and tables.

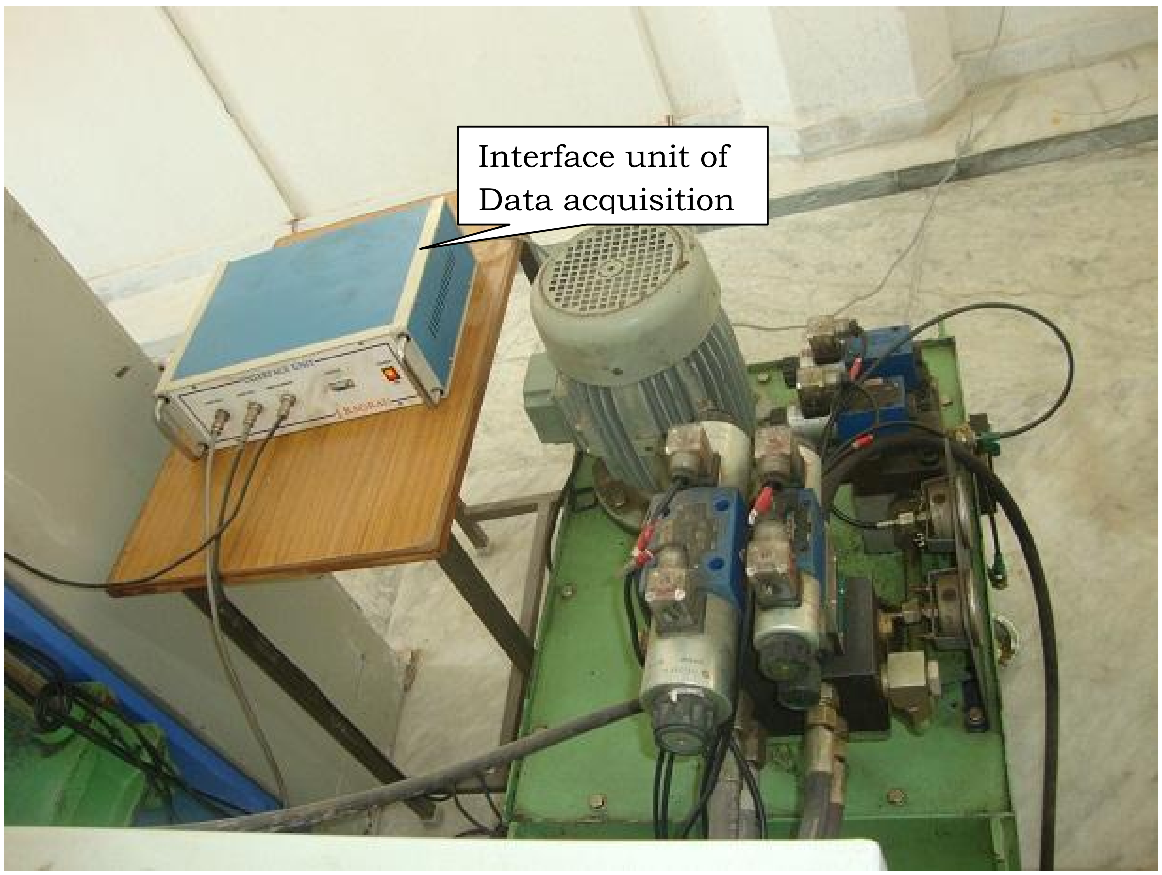

Fig 4.13. Interface Unit of Data Acquisition system

4.7 UNIVERSAL TENSILE TESTING MACHINE

The common tensile properties of these EDD steel sheets are determined by Uniaxial Tensile Tests on a 50 kN electronically controlled UTM. As shown in Fig.4.14, a furnace is mounted over the UTM in order to control the specimen temperature with the accuracy of $\pm 0.1^{0}$ C. The UTM is equipped with video extensometer also. This UTM is used to find out tensile properties of EDD steel at different temperatures

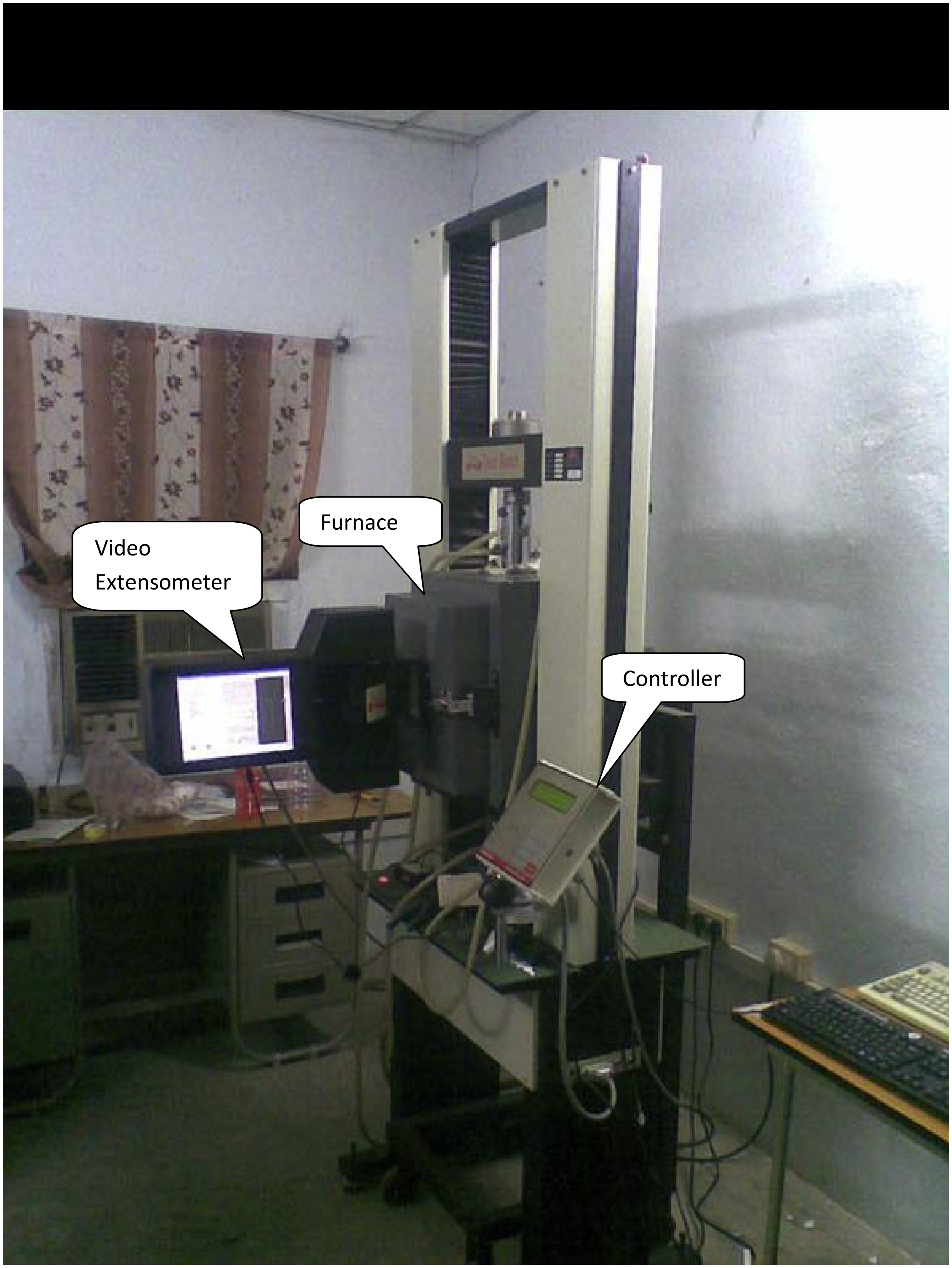

Fig 4.14 A 50 kN Electronically Controlled UTM with furnace

4.8 SCANNING ELECTRON MICROSCOPE

A scanning electron microscope (SEM) [Fig 4.15] is a type of electron microscope that images a sample by scanning it with a high-energy beam of electrons in a roaster scan pattern. The electrons interact with the atoms that make up the sample producing signals that contain information about the sample's surface topography

Fig 4.15. Scanning Electron Microscope

4.9 METALLURGICAL MICROSCOPE

Metals and alloys are polycrystalline, referred as grains. The metallographer records the crystalline structure to interpret the history of manufacture with the help of Metallurgical Microscope [Fig. 4.16].

Metals and alloys often contain features other than grains. The features of the non metallic inclusions and other flaws arise when the metal is put to cooling. These features should be observed and are to be used to study the characteristics.

Fig 4.16 Metallurgical Microscope with image capturing device

4.10 MICRO HARDNESS TESTER

Microhardness testing can be used to observe changes in hardness on the microscopic scale. A typical Micro hardness tester is shown in Fig. 4.17

Fig 4.17 Micro Hardness Tester

4.11 POINTED ANVIL MICROMETER

A digital pointed anvil micrometer which can measure wall thickness upto the accuracy of micron is used to measure variation of wall thickness from cup bottom to the top [Fig 4.18]

Fig 4.18 Pointed Anvil Micrometer

4.12. EXPERIMENTATION

A series of experiments are conducted to find out the behavior of flow forming under deep drawing setup of the press at different temperatures and different wall reductions. For this purpose, a double acting hydraulic press with blank and die heating system and data acquisition system is used.

Another series of experiments are conducted on 5 ton UTM on 2 mm thick EDD steel sheets at different orientations of roll directions are conducted to know the tensile properties at different temperatures.

4.12.1 Experimentation of Warm Forming on Deep Drawing Setup

EDD steel blank of different diameters from 58mm in the step of 1 mm and 2mm thickness each are cut-down on lathe by using special fixtures. The blanks are checked for the correctness of dimensions and geometric features. The plan of experimentation is to draw cups at three reductions (40%, 25% and 10%) and each set of experiments at three different temperatures (200^{0}C, 400^{0}C and 600^{0}C). Initially the die is coated with high temperature lubricant 'Molycote'. The press is initially switched on checked for the circulation of oil and checked for the movement of punch and blank holder. Data acquisition system is checked for its functionality. Then the water circulation for the Induction heating system of Die and the blank were checked for free flow. Then the die is heated to corresponding temperature of the blank and then blank is heated on the blank Heater (Fig 4.7). The temperatures are measured with non contact type infrared pyrometer. The hot blank is shifted to hot die in the exact position under the punch and blank holder is operated until the proper blank holding pressure is reached and then punch is operated immediately. The data acquired from the data acquisition system is saved.

4.12.2 Experimentation On Universal Testing Machine For Material Characterization

A series of experiments were conducted to determine the tensile test properties of EDD steel at different temperatures from 25^0C to 700^0C insteps of 25^0C. The specimens are prepared according to DMRL practice [77]. The specimen drawing is shown in Fig. 4.18

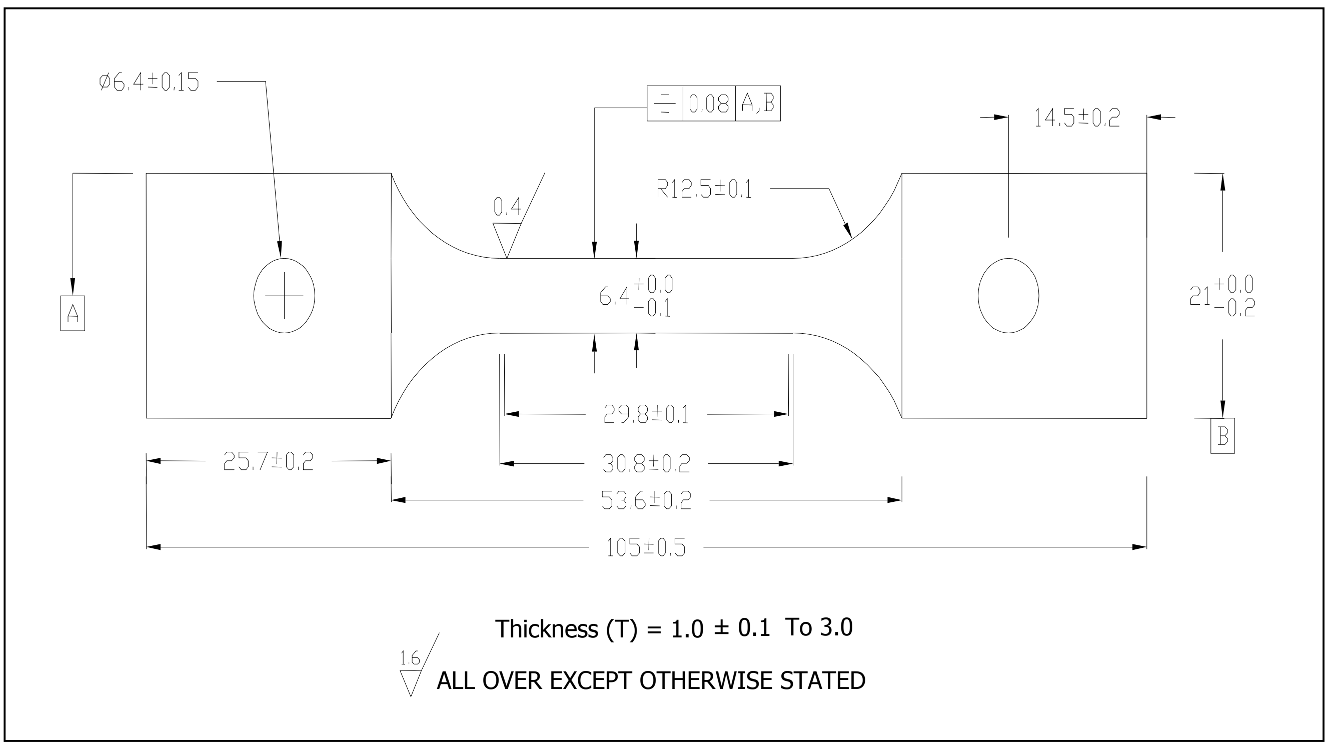

Fig 4.19 Specimen Drawing for Tensile test (DMRL practice)[77]

Fig 4.20 Specimen prepared according to Drawing for Tensile test

The specimens are cut down on wire cut EDM and checked the correctness of dimensions according to the standards. The specimens are cut down in three rolling directions i.e. 0^0, 45^0 and 90^0, each 28 pieces. The specimens are loaded in the UTM and the temperature is raised to pre determined value and then load is applied at constant speed 2mm per min. The load and displacement values are recorded by the data acquisition system of UTM. The furnace is allowed to cool after each test. Yield stress and Ultimate tensile stress, percentage elongation, Strength coefficient (K) and Work Hardening exponent (n) are computed.

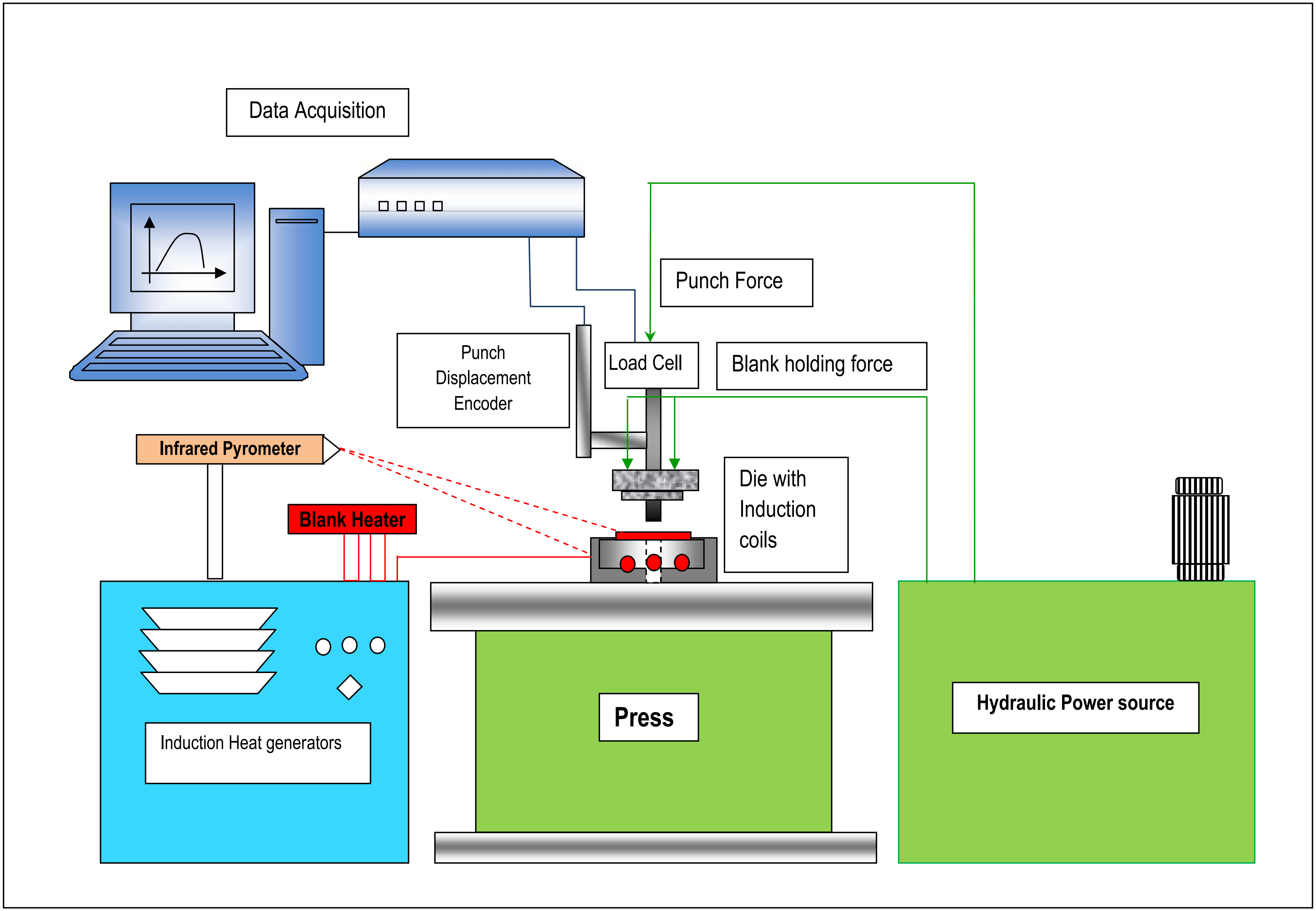

Fig 4.1 Schematic of Experimental setup for warm flow forming