Applications of sensors in manufacturing process of melt spun filament: A Review

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Abstract

Generally it has been observed that sensor is acting as a convertor which measures a physical quantity and transfers it into a signal that can be read by an electronic device. Almost all branch of Textile industry is well equipped with sensors in the present modern era. The application of sensor upgraded and enhanced productivity and efficiency of the machine with maintaining adequate quality and minimizing wastage in the subsequent process. Although sensor playing a very important role in controlling the accident during working on the subsequent processes. In this review article we show various sensors and its actual working in polyester and nylon manufacturing melt spinning process. This all sensors played an important role for optimizing process parameters for better productivity.

Keyword: sensors, measurement, melt spinning, extruder etc.

I. Introduction

The accurate measurement [1] of the data is an important basic necessity of any manufacturing industry. Here the measurement system is collecting all the required information and feeding it to the microprocessor for controlling the whole system. The measurement system mainly consists of sensors, transducers and signal processing devices. In general sensor is a device which gives a usable output from a specified measuring device. The main objective of the introduction of sensors is to carry out production process automatically with ease of process monitoring. With the help of sensor, alarm and light glows, the operator can find out failure part in any of the process in the manufacturing system and helps the operator for better productivity with preventive measures for avoiding deterioration in the quality of the end product The technological development [2] made automation a basic need for achievement of optimum quality for customer satisfaction without more human intervention. Most of the machineries of all sectors of textiles are dependent for achieving highest level of productivity with better efficiency and optimum quality. It has been observed [3] that it is difficult to maintain product uniformity and standard quality parameters in the manufacturing of micro-denier fiber with extrusion method, especially critical parameters has to be emphasized viz, continuous fiber diameter monitoring, constant and continuous control of temperature and pressure, and critical monitoring of polymer solution properties. These requirements are basic necessity for manufacturing of micro-denier fibers.

Types of sensors

1. Level sensor- Vibrating fork level sensor
2. Temperature Sensors- Thermocouples, Resistance Temperature Detector (RTD)
3. Pressure Sensors- Mechanical- bourdon tube, Electrical melt pressure sensor
4. Flow rate sensor - Rota meter
5. Speed sensor- Proximity sensor

Working Principle of sensors

1. Vibrating fork level sensor

The vibrating fork type level switch working principle is simple and effective. This makes vibrating fork type level switch reliable, cost effective and very popular for use in detecting the presence and absence of liquid and bulk solid materials. The vibrating fork type level switch working principle is based upon detecting the change in harmonic vibration frequency of the sensing element as a result of the presence of the target media. The vibrating fork type level switch [4] working principle uses a tuning fork shaped sensing element with two tines inserted into bin or tank where the target media is present. The tuning fork sensing element is placed into vibration at its natural resonant frequency by establishing motion in the sensing element or fork. The most common embodiment of the vibrating fork type level switch working principle is the harmonic vibration of the tuning fork sensing element is established using with piezoelectricity. When these piezoelectric elements or crystal are compressed or pulled under tension they generate an electrical signal. Conversely when electricity is applied to these crystals they produce motion. This motion is attached to the fork sensing element and vibration at the natural resonant frequency of the mechanical fork is created. A second piezoelectric crystal is used to transform the motion received from the first crystal back into an electrical signal. When the sensing element vibrates free in air the measuring system sees this as one state (material not present), when material is present, frequency of vibration is changes and the second crystal electrical signal changes, there by detecting the material presence

Fig. 1: Vibrating fork type level switch

2. Temperature Sensors-

Generally change in temperature shows the change in state of mechanical system as it can be observed with change in expansion or contraction of solids, liquids or gases, change in electrical resistance of conductors, semiconductors and thermo-electrical devices. The application of such a temperature sensors can be possible with the use of thermocouple, resistance temperature detector (RTD) etc.

2.1 Thermocouple:

The basic working principle of thermocouple (Fig. 2) depends on the theory that when a junction of dissimilar metals heated, it produces an electric potential related to temperature. Study of Thomas Seebeck (1821) concluded that when two wires composed of dissimilar metals are joined at both ends and one of the ends is heated, then there is a continuous current which flow in the thermoelectric circuit. The thermocouple consists of Chromel (90% nickel and 10% chromium), Alumel (95% nickel, 2% manganese, 2% aluminium and 1% silicon).

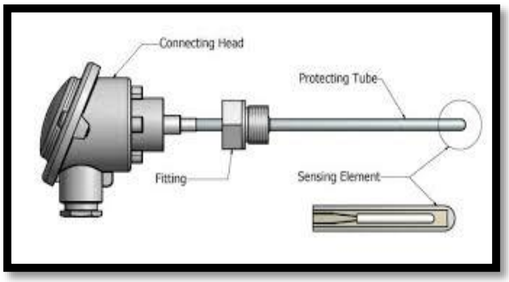

FIG. 2: THERMOCOUPLE

2.2 Resistance temperature detector (RTD)-

The basic working principle of Resistance temperature detector (Fig. 3) is, electric resistance of a metal changes due to change in its temperature. The heating of metal shows increase in temperature. The correlation is

$Rt = R0\ (1 + \alpha T)$ (2.5.1)

Where Rt is the resistance at temperature T ^{0}C and $R0$ is the temperature at 0^0C and α is the constant for the metal termed as temperature coefficient of resistance. The resistance [5] of a sensor is 100 Ω at 0 °C and it has a resistor element connected to a Wheatstone bridge (Fig. 3). The sheath protection is given to an element and the connection leads. The small amount of current is continuously passing through the coil. The change in the temperature causes the change in resistance of the coil and which is easily detected at the Wheatstone bridge. Thin films, wire wound or coil form of RTD is usually preferred for working. It is generally made of metals such as platinum, nickel or nickel-copper alloys. High temperature glass adhesive platinum wire in a ceramic tube is used to measure the temperature.

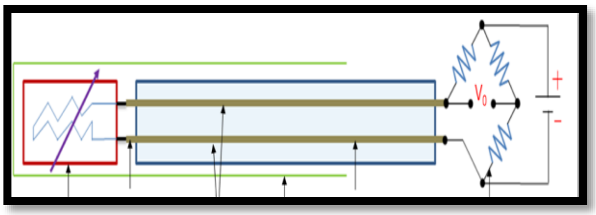

Fig. 3: resistance temperature detector

3. Pressure sensor

The accurate measurement of pressure [6] is required in many working areas, especially in many fluid mechanics related applications. The corrective measures of pressure are very much essential in appropriate determination of velocity, aerodynamic forces and moments. The differential pressure is usually measured by the measuring devices i.e. in respect with the atmospheric pressure, which is termed as gauge pressure. This pressure can be positive or negative depending on the atmospheric pressure. Main characteristics of pressure transducer are pressure range, accuracy, sensitivity and speed of response. Pressure range of transducer varies from almost perfect vacuum to several hundreds of atmosphere. The instruments used for pressure measurement are divided into the following groups.

1. Mechanical Pressure gauges with elastic sensing elements
2. Electronic melt Pressure transducers with secondary transducer

3.1 Mechanical type pressure sensor- "C" type bourdon tube

The mechanical C type bourdon tube pressure transducer (Fig. 4) is one of the oldest sources of measuring device, which is generally [7] a length of metal tube of elliptical cross section and having C shape structure. One end is left free and the other end is fixed and is open for the pressure source to be applied. With same length and with same other parameter it has been observed that tube of elliptical cross section has a smaller volume than a circular one and during connection with pressure source it is likely to accommodate more of the fluid. This produces maximum displacement at the free end for resultant of all reactions. The change in subtended angle at the center by a tube is proportional to the change of internal pressure and within the limits of proportionality of the materials, which is the displacement of the free end is proportional to the applied pressure. The sensitivity of the Bourdon tube is judged from the ratio between major and minor axes. The larger the ratio, higher is the sensitivity. Materials used in the manufacturing of Bourdon tube are Phosphor bronze, Beryllium bronze or Beryllium Copper.

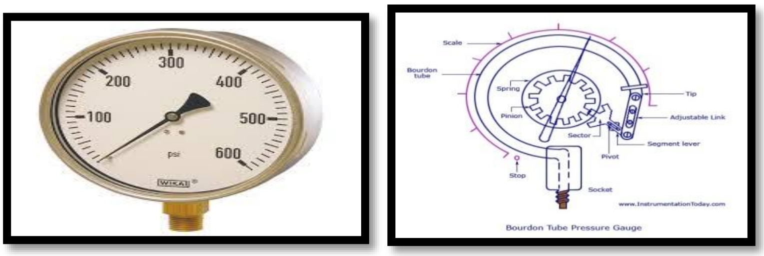

Fig. 4: mechanical "C" type bourdon tube pressure transducer

3.2 Electronic melt Pressure transducers with secondary transducer

Electronic melt pressure sensors or transducers are accurate and versatile instrument. These sensors have metal diaphragm flush with extruder barrel wall. The motion of this lower diaphragm is transferred to the elastic electronic displacement transducer which is located some distance away from the process heat, by a push rod or fluid filled capillary tube (Fig. 5). The fluid filled capillary or push rod mechanically [8] deforms the upper elastic displacement transducer, and an electrical signal proportional to the melt pressure is obtained. Bonded foil type strain gauge pressure transducer are used in electronic melt pressure sensor, although other electronic displacement transducer, such as piezoelectric elements are widely used. The electrical output pressure signals from these transducers can be displayed, recorded or fed to control system. Electronic pressure transducers using the fluid capillary system to transfer lower diaphragm deflections to the electronic sensing element, have certain advantages over the push rod type. This transducer is insensitive to mounting torque, has an increased diaphragm fatigue life, and often gives greater accuracy. However, the liquid mercury filled in the capillary system, approximately 0.003 cubic inches per transducer, is coherence to the processor of certain products such as a food packing. Lower diaphragm rupture cloud result in extruded contamination, not a problem encountered with push rod transducers. Unfortunately, push rod transducers are sensitive to mounting torque and are said to be sensitive to ambient temperature change.

Specification – Pressure range -500 bar, Input- 24 VDC,
Output- 4-20 mA, Calibration- 80% FS

FIG. 5: ELECTRONIC MELT PRESSURE SENSOR

4. Flow rate transducer- Rota meter

Most of the time, the industrial control loops are maintaining [9] the flow rate of incoming fluid and gases in order to achieve the accuracy in any objective. For this the accurate measurement of flow rate is very much essential. There are different types of flow rate measuring technique that are used in industries, such as orifice meter, venture-meter, Pitot tube, Rota meter, turbine flow meter, ultrasonic flow meter, electromagnetic flow meter etc. The Rota meter is widely used for flow rate measurement due to its simple construction and lower cost. The meters consist, of a float or a bob within a vertical tapered tube to an increasing cross section at outlet. The air or fluid entering trough the bottom passes over the float, which is free to move only in the vertical direction. For a given flow rate, the float remains stationary [10], when the weight of the float is balanced by the buoyancy and drag force. The annular area between the float and the vertical tube varies continues within vertically displacement of the float. When the float is in particular position for a flow rate, the differential pressure varies with the square of the flow rate. The movement of float is sense by secondary transducer or proximity sensors to convert it into electrical signal for automatic control.

Fig. 6: Rota meter

5. Speed sensor- proximity sensor

Many times it has been observed [11] that it is very essential to measure and sense the shaft speed. Some of the common devices used for this purpose are shaft encoders (rotary pulse generators), proximity sensors, and photoelectric sensors. These devices collect the speed data in the pulses form and send it to the measuring device. Generally following two factors affecting the quality of speed data, one is number of pulses per revolution of the shaft, which is referred to as PPR. The better resolution obtained with higher PPR values. Second the symmetry of pulses, as the symmetry in one pulse to the next can shows the consistency in the RPM readings. The accurate measurement of pulses can be carried out with proximity sensors by providing medium or low resolution sensing device, depending on the number of pulses measured per revolution. The accurate measurement can be carried out by applying proximity sensor to sense the teeth on a gear. The sensing can be carried out with options for 60, 120, or 240 PPR, and the measured pulses can be clearly defined and symmetrical. In absence of the gear, the proximity sensor can sense the bolt head which is attached to the shaft. But the main drawback of this method is the low PPR (low resolution). The resolution can be improved with the use of more than one bolt head but pulses are often inconsistent and not symmetrical. The monitoring of RPM when carried out with frequency measurement, the number of pulses being sensed per revolution (PPR) is the key factor. For high PPR sensors, the method works well but for low PPR sensors works poorly. The following examples shows how RPM and pulse frequency can be affected,

With a 600 PPR sensor, the equation becomes:

$$\text{RPM} = \frac{\text{Pulse Frequency x 60}}{600}$$

$$= \frac{\text{Pulse Frequency}}{10}$$

$$= \text{Pulse Frequency x 0.1}$$

For a pulse frequency of 1 Hz, the shaft speed will be 0.1 RPM.

For a pulse frequency of 2 Hz, the shaft speed will be 0.2 RPM
For a pulse frequency of 3 Hz, the shaft speed will be 0.3 RPM. The increase of pulse frequency in 1 Hz, the RPM indication will change by 0.1 RPM. With a 600 PPR sensor, the shaft speed resolution is 0.1 RPM, which meets most application requirements.

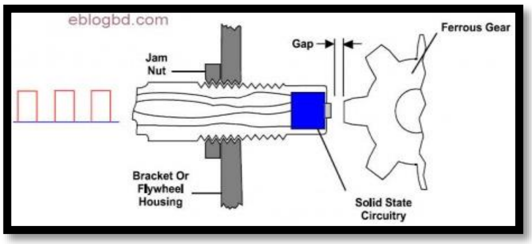

Fig. 7: speed sensor

Application of sensors or transducer in process
In general filament formation [12] can be carried out with three different spinning method i.e. melt spinning, wet spinning and dry spinning. In each spinning method, various process parameters are controlled, such as temperature, pressure, speed, time, flow rate, chip level, etc., in the formation of filament. In melt spinning process, melting temperature and pressure are the most important process parameter for optimum productivity and quality. Accurate control the process parameter can improve product quality, production; protect personnel and equipment from damage. In melt spinning of polyester, nylon 6, polypropylene following process is used:

1) Feeding of chip
2) Drying of chip (in case of polyester)
3) Extrusion
4) Spinning beam
5) Winding

These all process is control automatically with the help of sensors and control system such as PLC and SCADA. Process wise control description is follows:
Feeding process-
In feeding process solid chip of polymer is put into big Hooper and then transfer to the dying and melting process.

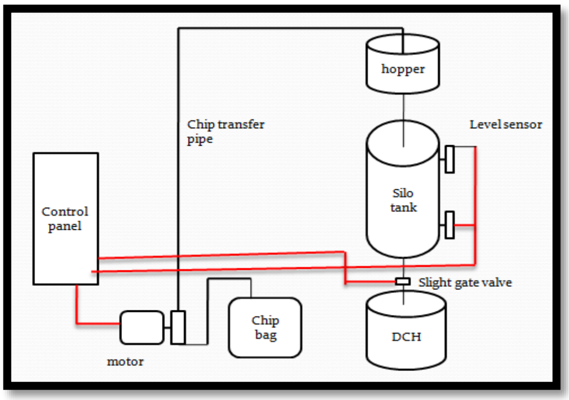

Fig. 8: automatic control feeding system

Sensors with control parameters

I. Conveying air flow rate- Rota meter
II. Nitrogen flow rate (in case of nylon)- Rota meter
III. Motor speed- proximity sensor
IV. Chip level in silo tank- vibrating fork level sensor
V. Nitrogen and air pressure- bourdon tube

In automatic feeding system one end of chip [13] transfer pipe is put into chip bag and another end is joining to the vacuum air pipe. With help of motor, fan is rotated and vacuum is created. Due to vacuum air chip is suck and transfer from bag to hopper. Then chip are fall into next silo tank, contain level sensors. This sensor senses the level of chip in the tank. When chip reaches at top of the tank, sensor senses and forwarded the signal to the controller. Controller stops the motor and at the same time chip feeding stop. When chip is at lower level, the sensor senses and forwarded signal to the controller. Controller starts the motor and feeding is start. Conveying air and nitrogen flow rate, pressure is control and maintain as per setting.

Drying of chip (in case of polyester)-

Drying is the process to dry the chip to reduce moisture level. In case of polyester chip is transfer to the dryer to reduce chip moisture at 0.004%. In case of Nylon 6 drying process is eliminated.

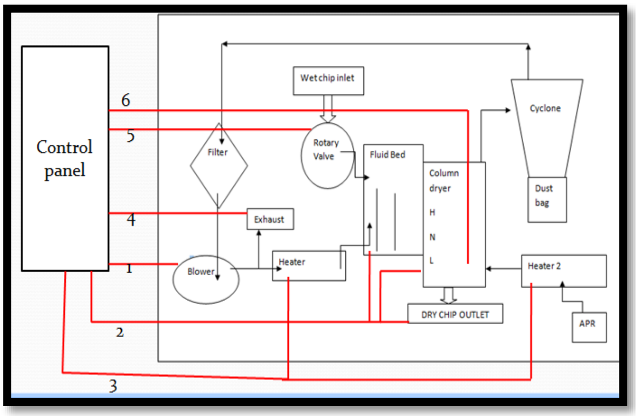

FIG. 9: AUTOMATIC CONTROL DRYER

CONTROL PARAMETER WITH SENSOR-

I. Blower speed- speed sensor
II. Crystallization air temp, Colum air temp and dry chip temp- temperature sensor
III. Heaters temperature- temperature sensor
IV. Outlet air temperature- temperature sensor
V. Chip level-Level sensor
VI. Air pressure in chamber- pressure sensor

In drying process, temperature [14] is control by resistance temperature detector. Its resistance increases when temperature increases. In dryer Crystallization, the sensors are controlling following parameters viz. air temperature, Column air temperature and dry chip temperature, Heaters temperature, outlet air temperature. Sensors are sensing the changes in set temperature and forwarding these signals to the controller. Controller automatic control heater voltage as per required. The chip level in column is sensed by vibrating fork sensor at three different level of column on lower, middle, high stage. When chip reaches at high level then rotary valve automatically closed by controller signal and feeding is stop. Chip at lower level then rotary valve open by controller and feeding is start. Level is maintained at middle level. The flow of air is controlled by Rota meter and when air flow is changes, the movement of float in Rota-meter happened. Movement of float is sense by secondary transducer and converts into electrical signal. Signal is forward to controller and automatically control blower speed and maintain flow rate of air. Blower speed is sense by speed sensor. Air pressure is indicated by mechanical pressure gauge.

Extrusion and spinning beam-

In extrusion process solid polymer [15] is melted and form melt polymer solution. This solution is easily passed through spinneret and form filament. In this process material passed through extruder having screw with heating arrangement outside of barrel. Extruder consist 3-4 zone name as feeding, compressing, mixing, metering. Temperature and pressure plays very important in melting.

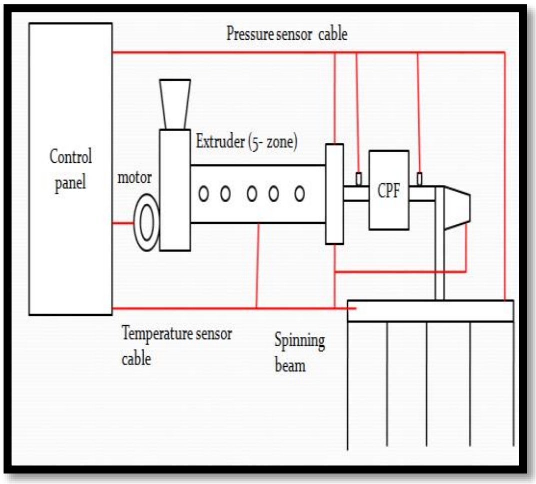

Fig. 10: line diagram of extruder and spinning beam

Control parameter

I. Melt temperature at- extruder zones, beam, after CPF, measuring head.
II. Dowtherm boiler vapor temperature and pressure
III. Melt pressure at- measuring head, before and after CPF, beam.
IV. Screw speed and melt pump speed

In extruder and spinning beam temperature is control by resistance temperature detector. Its resistance increase when temperature increases. In extruder melt temperature is sense at 5 zone, measuring heads are Crystallization air temperature, Column air temperature and dry chip temperature, Heaters temperature, outlet air temperature. Sensors are sensing changes in set temperature, and forwarding these signals to the controller. As per required temperature the controller automatically control heater voltage and maintain that temperature. In this process pressure is measure at extruder meter head and continues polymer filtration unit. Electronic pressure sensor probe is fitted at barrel wall of extruder and continuous polymer filtration unit. When change in pressure at metering head, sensor sense and forward signal to the controller. Controller automatically control the speed of screw, as when pressure is lower, speed is increases and vice versa. Speed of screw is sense with help of proximity sensor. In continues polymer filtration unit two pressures are fitted at inlet and outlet position. These sensors sense pressures at both position and find delta pressure (pressure difference). If delta pressure is above 100 bar it gives signal of filter change. Speed of melt pump is also control for uniformity in filament. In Winding process process filament is winding on package [16] with uniform speed and tension. Winding process is fully automatic. It is controlling with PLC and sensor. Pneumatic actuators is used for control any operations.

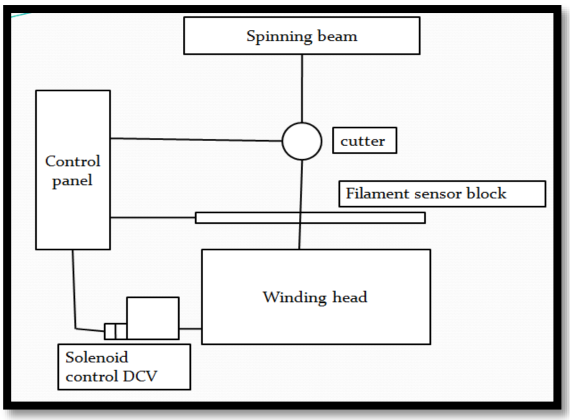

Fig. 11: automatic winding of filament

Accuracy in speed is most important in filament winding. Speed is directly affecting on the stretching or orientation of the filament. Speed and position of actuators are sense with help of proximity sensor. The yarn is continually sense with the help of optical sensor. If yarn is break during process, sensor is forwarding signal to the controller. Controller activating the cutter and cut yarn and suck into pipe. Pneumatic actuator system used for following operation in winding- CR head up/down, Pusher forward/backward, Arm forward/backward, Arm open/closed, Traverse separator, contact roller separator, Treading guide, Bobbin chuck release, Spindle break filament cutting, Stop motion at filament break .

Conclusion

Although from the study it can be concluded that sensors are playing a vital role in controlling the process parameter of melt spinning of filament yarn and optimistic characteristics values can be obtained with the application of sensors. The temperature and pressure directly affecting production and quality of melt spun filament, which can be easily judged, control and apply as per the condition required. Ease of process is the most important advantage possible with the application of sensors. The high level of accuracy and automatic control resulting in reduction of man power requirement and ultimately reduces labour cost.

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