1.1 Faults and Their Diagnosis

A failure in equipment of production line hampers not only the productivity but also paralyses the services to customer, and may even lead to safety and environmental problems that could destroy the organization image in the market. This emphasizes the need of practicing timely maintenance activities in manufacturing mechanisms of organization. Such activities can sustain the reliability of product equipment, improve the product quality, enhance productivity and undertake the safety requirements. However, maintenance activities have been historically regarded as a necessary evil by the various management organizations. Since cost of maintenance forms a large dividend of the total operating and production costs in capital-intensive industries. Sustaining the productivity is a key strategy of manufacturers to exist on the drastic competition of global market. In order to keep up the productivity, manufacturers need to reduce the manufacturing costs by following good maintenance strategies. Consequently, a good maintenance strategy plays a crucial role in the existence and development of the organizations. In back, with the fast development of technology, the equipments are becoming more and more complex. The traditional maintenance strategies such as corrective maintenance and prescheduled maintenance alone cannot guarantee the functional operation of equipments and are progressively replaced by intelligent maintenance strategies in which condition based maintenance is one of the delegates.

Condition based maintenance has been defined as the maintenance actions, which are based on actual conditions of equipments obtained from nondestructive inspections, operations and condition measurements. The equipment condition is accessed under operation for making conclusions about equipment failure and the necessity of effective maintenance actions to avoid
the consequences arising from the failure. The use of condition-based maintenance systems ensures that the condition of equipment is always monitored, and alarming limitations can be indicated if the condition exceeds predefined levels. In condition based maintenance system, the fault diagnosis and condition prognosis are crucial components, which have been considerably received attention from the community of Researchers and R & D departments of Industries [1].

Fault Diagnosis is the ability to detect fault, isolate the component under failure state, and decide on the potential impact of failed component on the health of the system. While condition prognosis is defined as a capability to foretell the future states, predict the remaining useful life, i.e. the time left for the normal operation of machine before breakdown occurs or machine condition reaches the critical failure state.

Machine failure has direct product-quality implications and may cause loss of throughput resulting into significant financial losses. Therefore to improve productivity and cost effectiveness, it may become necessary to develop intelligent systems that will provide accurate and reliable fault detection, diagnosis and prediction, and can suggest preventive actions for delicate modern machinery. Fault Detection and Diagnosis (FDD) has its own significance in Engineering Systems, and deserve further attention in view of the increasing complexity and quality performance of modern machinery. For fairly simple systems, simple sensing or observation and one's intuition usually provide sufficient diagnosis of a faulty condition rather quickly. However, modern machines with complicated structural configurations; for example, chemical plants, power stations, and surface mount machines (SMT), Textile Industry etc have higher fault occurrence probabilities.

The appropriate fault diagnosis becomes difficult task with traditional methods. This is because the modern machineries involved advanced
technologies and their hardware and software architectures tend to be very complex.

Depending on the nature of industry the maintenance costs can go up to 40% of the costs of goods production. For example, maintenance costs as a percentage of total value-added costs reported in [2] are as shown in the table 1.1.

**Table 1.1: Maintenance costs of typical industries**

<table>
<thead>
<tr>
<th>Type of Industry</th>
<th>Maintenance costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Textile Industries</td>
<td>25-55%</td>
</tr>
<tr>
<td>Mining Industries</td>
<td>20-50%</td>
</tr>
<tr>
<td>Primary metal Industries</td>
<td>15-25%</td>
</tr>
<tr>
<td>Processing and Manufacturing Industries</td>
<td>3-15%</td>
</tr>
</tbody>
</table>

Knights et al [3] studied open-pit mining operations in Chile - the world’s primary copper producer. They found the maintenance costs were estimated to be 44% of total mine production costs. Generally 20-40% of these maintenance costs are related to the repair of major components. Therefore, major system repair costs indirectly account for 9-18% of the total operating costs of an open-pit mining operation. Also, for equipment manufacturers and distributors, system repair and maintenance costs are the major causes of liabilities through warranty programs and repair plus maintenance contracts, especially when taking into account the use of rebuilt system is of growing interest to the industry both on a rental or lease basis.

Due to complex manufacturing plants in textile, the probability of fault occurrence is more as reported in Table 1.1. According to survey [5], the faults are basically classified into different categories like mechanical faults,
electrical faults and electronics hardware faults as depicted in the Table 1.2 along with their probabilities.

<table>
<thead>
<tr>
<th>Type of Faults</th>
<th>Occurrence (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical faults</td>
<td>40-60%</td>
</tr>
<tr>
<td>Electrical faults</td>
<td>50-70%</td>
</tr>
<tr>
<td>Electronics Hardware faults</td>
<td>40-70%</td>
</tr>
</tbody>
</table>

The mechanical faults occur due the wear and tear, unexpected force and tension. While electrical faults occur due to electrical fluctuation, overload and overvoltage on electrical machines such as motor etc. The electronics hardware faults occur due to short circuit, electromagnetic interference, power supply spikes etc.

The recent survey of effectiveness of maintenance management in manufacturing industry indicates that one third of all maintenance cost is wasted as result of unnecessary and improper maintenance activities. Additionally, with the increase of mechanization and automation, many modern plants installed with the flexible computer controlled automatic and unmanned equipments, the maintenance costs have gone up substantially. Consequently, an efficient and reasonable maintenance strategy is one of the prime needs of organizations to meet their overall objective of minimal costs [3].

Traditionally, maintenance strategies in industry are broadly classified into two categories, viz. [1, 4]

1. Corrective Maintenance
2. Preventive Maintenance
Corrective maintenance, also known as breakdown maintenance is carried out merely after the occurrence of an obvious functional failure, malfunctioning or breakdown of equipment. It restores the functional capabilities of failed or malfunctioning equipment either by repairing or replacing the failed component. Corrective maintenance is a reactive approach to maintenance, because the action is triggered by the unplanned event of an equipment failure. Preventive maintenance involves scheduled maintenance and Condition Based Maintenance (CBM). Scheduled Maintenance is performed periodically at predetermined interval to prevent the functional failure by replacing critical components before the end of their expected useful lives. CBM is a method used to reduce the uncertainty of maintenance activities, and is carried out according to the need indicated by equipment condition. Unlike the strategies mentioned, CBM does not normally involve an intrusion into the equipment and actual preventive action is taken only when an incipient failure is believed being detected.

The variation in costs with number of maintenance events is depicted in Fig.1.1. With corrective maintenance, even though the maintenance cost is low, its total cost is still high due to the operational failures. Conversely,
preventative maintenance practice produces low operation costs. However more preventative actions produce greater maintenance costs. Evidently the condition-based plan is the most efficient in terms of total operations costs.

1.2 Fuzzy Fault Diagnosis Methodology (FFDM)

For better establishment of architectural characteristics and easy development, the target problem can be decomposed into sub-modules, sub-
modules into policies as depicted in Fig. 1.2. The level 0 corresponds to the fault detection module for system while the level 1 includes the sub-modules for different category like Mechanical, Electrical or Electronics fault. Sub-module for Electrical Fault is subcategorized in different policies like short circuit fault, open circuit fault or phase detection fault form level 2. Further the level 3 intends the exact nature and reason for fault detection using the fuzzy module. For example in open circuit fault the overall system may total breakdown or in partially running state. The fuzzification module is applied in level 3 using Universe Of Discourse (UOD), membership function and partition. The model designed based on fuzzy logic usually consist of a number of fuzzy if-then rules expressing the functional mapping between inputs and desired output. In these models the inputs are fuzzified, membership functions are created, association between inputs and outputs are defined in a fuzzy rule base and fuzzy outputs are recomputed as crisp values.

Generally fuzzy modules work from outside to inside i.e. first a good understanding of system behavior is developed and then trial simulations are carried out with respect to fuzzy surface, followed by performance validation. Thus procedure is best applied from policies to sub-modules and then to overall fuzzy module [6].

Fuzzy logic allows items to be described as having a certain membership degree in a set. This allows a computer, which is normally constrained to 1 and 0, to delve into the continuous realm [7]. During fault diagnosis, there exist several situations in which component conditions is not obviously “good” or “bad”, but may fall into some intermediate range. E.g. component condition may be more or less good or bad [8-10].

Fuzzy logic has gained wide acceptance as a useful tool for blending objectivity with flexibility, particularly in the area of process control. Fuzzy logic is also proving itself to be a powerful tool for knowledge modeling. In condition monitoring and diagnostics applications the knowledge pertaining to
fault occurrence can be used on the apparatus of fuzzy logic. Though the Researchers have reported the results which show a great degree of success, there remains a strongly subjective component to the analysis procedures. The membership functions are usually designed in a relatively subjective manner based on a preliminary inspection of the data being analyzed. The work reported by these Researchers involves the use of fuzzy logic principles in conjunction with established and accepted statistical data analysis, and condition assessment standards. The procedure used is shown to be a truly objective method of categorizing vibration signals and thereby providing a means of automatically detecting and diagnosing machinery conditions [11-14].

Fuzzy logic provides a method of reducing and explaining system complexity. It deals with system uncertainties and ambiguities in a way that mimics the human reasoning. Fuzzy logic allows the membership of a variable within a group to be estimated with a prescribed degree of uncertainty. In this way, the application of fuzzy logic to machinery fault diagnosis naturally allow the membership of dynamic signal frequency spectra from an unknown source to be determined with respect to a set of spectra representing particular faults [11]. Using fuzzy membership functions that are similar in shape to the distribution of data within the dynamic signal would be relatively easy to implement. This would electively customize the procedure for use in a wide variety of fault diagnostic approaches and thereby greatly enhance the overall quality maintenance performance of system [12].

A typical Multi Input Single Output (MISO) fuzzy logic system performs a mapping using four basic components: rules, fuzzifier, inference engine, and defuzzifier. A typical fuzzy logic system maps crisp inputs to crisp outputs via a fuzzy processing space. Once the rules driving the fuzzy logic system being fixed, the fuzzy logic system can be expressed as a mapping of inputs to outputs. Rules can be elicited from Experts or consolidated from
numerical data. In either case, engineering rules are expressed as a collection of ‘IF-THEN’ statements such as-

“If $u_1$ is HIGH, and $u_2$ is LOW, THEN $v$ is LOW”

To formulate such a rule we need an understanding of following-

1. Linguistic variables versus numerical values of a variable e.g. HIGH versus 3.5%.
2. Quantifying linguistic variables e.g. ‘$u_1$’ may have a finite number of linguistic terms associated with it, ranging from NEGLIGIBLE to VERY HIGH, which is performed using fuzzy membership functions.
3. Logical connections between linguistic variables e.g. AND, OR etc.
4. Implication of rules such as ‘‘IF A THEN B.’’
5. Compilation of multiple rules.

The fuzzifier maps crisp input numbers into fuzzy sets. It is needed to activate rules that are expressed in terms of linguistic variables. An inference engine of the fuzzy logic system maps input fuzzy sets to output fuzzy sets and determines the way in which the fuzzy sets are combined. In several applications, crisp numbers are needed as an output of the fuzzy logic system. In those cases a defuzzifier is used to calculate crisp values from fuzzy values.

The main goal has been to provide maintenance engineers continuous online information about the systems health which would guide them to formulate decisions. This information needs to be given at an incipient stage in order to avoid any further serious damage to the system. This also helps in avoiding false triggers and missing alarms. Fuzzy logic when used in combination with analytical methods like non linear observer can enhance the performance domain. It acts as a good extension to upgrade the system. Moreover while fuzzy rule are set up, the fuzzy reference rule-set generated is used for representing the normal working condition, which is supposed to be the preliminary fuzzy reference rule-set. Simulation results reported in [14]
showed that whatever fault type the plant generates, its symptoms always depart from the characteristics of the fuzzy reference rule-set standing for the normal working condition. And thus, with the credit-degree representing the normal working, Researcher judged whether the plant working condition is normal and further obtain the degree of fault. This study seems to be helpful to determine the existence of fault and to report the system conditions to the data depository system. It has been felt that it is essential to develop a fuzzy based mechanism to identify the fault type and predict the equipment remaining life.

1.2.1 Why Fuzzy Logic in Fault Diagnosis for Textile Industry?

✓ The Fault in machine is uncertain.
  ▶ Fuzzy logic allows the treatment of uncertain data.

✓ The machine fault detection involves heuristic knowledge and experience.
  ▶ Fuzzy logic allows expressing human knowledge in linguistic way.

✓ Machine parameters are non-linearly interdependent. This is one of most critical parts of fault diagnosis.
  ▶ Fuzzy Logic is a calculus of complexity that helps easily model such dependencies amongst various parameters.

✓ The fault detect information is imprecise in nature on several phases of the fault diagnosis.
  ▶ Fuzzy Logic allows context dependent modifications, permitting to fine tune with new data and knowledge at different levels of attributes.
In case of Textile Industry control it is difficult to keep track of changes in the parameters reinforced by change in other parameters.

- Fuzzy Logic allows mapping values of different criteria and inferring overall conclusion that helps to foresee the consequential changes in one parameter by another.

- Lack of proper communication and language between the ‘Technical Expert’s and the ‘operator’ of the textile machinery with opposing views on many approaches and control parameter specifications.

- Fuzzy Logic dilutes the communication problem between the ‘Operator’ and ‘Technical Expert’ by offering languages at both the levels of expertise.

1.3 Literature survey

Ample literature exists on the Faults in Textile Industry and their consequential analysis based on conventional fault detection techniques. Over the last decade investigations have been made on possible usage of alternative ways of fault detection and its diagnosis. This section includes the literature on past Research over fault and fault detection, machinery fault diagnosis, condition monitoring, reliability, maintenance, Artificial Intelligence and fuzzy techniques. It has helped us to formulate the present research problem and go further with investigation by exploring the Fuzzy Logic Inference in the process of fault finding and procedural diagnosis in Textile Industry.

M. B. Celik and et al in [15] have reported a complementary fuzzy logic based fault diagnosis system developed to diagnose the faults of an Internal Combustion Engine (ICE). System was incorporated with an engine test bench. The input variables of the fuzzy logic classifier were acquired via a data acquisition card and RS-232 port. The rule base in this system was developed by considering the theoretical knowledge, the expert knowledge, and the
experimental results. The accuracy of the fuzzy logic classifier was tested by experimental studies which were performed under different fault conditions. Using the developed fault diagnosis system, ten general faults observed in the internal combustion engine were successfully diagnosed in real time.

Many Engineers and Researchers [15-19] have focused on incipient fault detection and preventive maintenance, which aimed at preventing occurrence of motor faults. The work was focused on different motor failure mechanisms, causes of stator and rotor failures, analyses of these failures, methodologies to determine whether a motor is suitable for extended service, test methods, the test equipment needed, application and limitations of these test procedures, data gathering, specific benefits, and costs [20,21]. In addition to developing motor protection schemes in reaction to faults due to disoperation, disturbances, sudden failure, etc., motor incipient fault detection problems have also been attracting significant attention and creating interest. Online monitoring of induction machines in critical applications has been increasingly demanding to improve their reliability and to minimize catastrophic failures. Microprocessor based monitoring systems are of particular interest because they can be used for regular analysis of machine variables and to predict possible fault conditions, so that preventive maintenance can be organized in a cost effective manner. Researchers have addressed the importance and economic benefits of online motor monitoring and fault detection approaches [21, 22].

General methods of cost–benefit analysis have been applied to investigate the financial viability of such systems. Methods for the evaluation of the improvement of machine reliability by monitoring of systems have been discussed by D. J. T. Siyambalapitiya and P. G. Mclaren in [23]. Different invasive and noninvasive approaches for motor incipient fault detection/diagnosis have been reported in [15-19]. Many of the motor incipient need the expensive monitoring microprocessor based equipment.
With proper monitoring and fault detection and diagnosis schemes, the incipient faults can be detected in their early stages and thereby preventing actions could be initiated. Thus maintenance and downtime expenses can be reduced, and reliability can be improved. System identification and parameter estimation have been proposed for fault detection and diagnosis in motors [15-18, 24, 25]. As opposed to conventional techniques, where expensive equipment or accurate mathematical models are required, Fuzzy Logic and Artificial Neural Network (ANN) technologies can be used to provide inexpensive yet effective fault detection mechanism alternatives as suggested by P. V. Goode and M. Y. Chow in [26].

The very purpose of Fuzzy rule base modeling is to identify the structures and the parameters of a fuzzy if-then rule-base, so that a desired input/output mapping could be properly achieved. Recently, using adaptive networks to fine tune membership functions of a fuzzy rule-base has received more attention [33]. Many methods have been proposed for implementing and optimizing fuzzy reasoning via ANN structures [27-32].

The condition monitoring, fault diagnosis and detection of electrical machines can be performed using simple voltage and current sensors [35]. The monitoring of industrial systems may be split into two phases. The first forms the faults detection followed by their diagnosis in the second phase. The diagnosis must allow the localization and the identification of the causes of these faults. It should make it possible starting from the observation of symptoms to go back to the causes explaining these symptoms. It is thus assumed that there is a causal relation of implication between the causes and the effects observed: causes imply effects (symptoms). However, logic does not make it possible to provide information on the antecedent from the consequent. The basic idea developed here has been thus to put forth an explanatory assumption on the antecedent in comparison with the observations relative to the consequent [36].
Yi Lu and et al. [37] described a fuzzy diagnostic model that contained a fast fuzzy rule generation algorithm and a priority rule based inference engine. The fuzzy diagnostic model was implemented in a fuzzy diagnostic system for the End-of-Line test at automobile assembly plants and the implemented system has been tested extensively.

Lappage J. [38] investigated end breaks of eight kinds of singles yarn in both spinning and weaving process. He identified the end breaks by their causes and recorded them during plain weave weaving. End breaks were found to be due to failed splices, abrasion failure and thin places. The incidence of thin-place breaks was found to increase with increasing irregularity of the yarn, and as the linear density of the yarn decreased. The most significant cause that affected the yarn count limit for acceptable weavability was the thin-place end breakage rate. And the thin-place end breakage depended on the evenness of the yarn. It was shown how to predict the thin-place end breakage rate from the yarn, fabric and loom parameters.

The effects of yarn properties on weft yarn velocity along the tube has been investigated by Kayacan et al. [39], and developed a weft insertion system in air jet weaving looms controlled using Fuzzy Logic. The effects of yarn linear density (tex) and value of twist coefficient on the change in weft yarn velocity were determined by the fuzzy logic system. Experimental data and expert knowledge was used in the establishment of the fuzzy logic model and the construction of basic principles. The results obtained from the fuzzy logic model were compared with the experimental results.

Iwaki et al. [40] discussed the yarn tension mechanism in nozzles both numerically and experimentally. Air flow rate in some kinds of nozzles were measured experimentally. The drag force acting on the yarns with different yarn structure and yarn count was measured. The yarn tension obtained was compared with the value calculated from the drag coefficient based on Reynolds number.
Tensile strength and yarn count of melt-spun fibers forms important parameters that decide the quality of cloth. *Kuo et al.* [41] reported the prediction of these parameters in anticipation to achieve good quality of cloth based on Fuzzy Reasoning. In this paper, the input variants were the extruder screw speed, gear pump speed and winding speed. Output variants were the tensile strength and yarn count (denier) of as-spun fibers. Triangular membership functions were used for both input and output fuzzy sets. Mamdani’s ‘min-min-max’ fuzzy inference approach was adopted.

*Xu et al.* [42] applied fuzzy logic for color grading of cotton into different classes based on Rd, b values obtained from HVI color measurements. They selected five fuzzy sets for the input variable Rd and six sets for b. The output variable, which was color grade, had five fuzzy sets. A Gaussian membership function was chosen for the input fuzzy sets and a triangular membership function was used for the output fuzzy sets. The centroid method was applied to defuzzify the output. It was a novel and fascinating approach using Fuzzy Logic in the Textile Industry employed for color based cotton grading.

In the dye process controlling of concentration, pH and temperature is very essential. *Huang and Yu* [43] investigated the use of Fuzzy Logic Controller in dye process for smooth control of these variables. Fuzzy control relies on a set of rules. These rules, while superficially similar, allow the input to be fuzzy, i.e. more in the linguistic form as humans express knowledge. Thus, a Power Engineer might refer to an electrical machine as “somewhat secured” or a “little overloaded”. This linguistic input can be expressed directly by the Fuzzy Sets. Therefore the natural and linguistic format greatly eases the interface between the Engineer Knowledge and the Domain Expert. Furthermore, infinite gradations of truth are allowed, a characteristic that accurately mirrors the real world, where decisions are seldom “crisp”.

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During fault diagnostic process, we come across several situations where an symptoms are not clearly expressible, the fault condition is not obviously “good” or “bad” rather falls in quandary scale between good and bad [11, 12]. In many research papers it has been accentuated that the induction motor condition interpretation is by and large a fuzzy concept [13]. During the past few years simulation software is lending a hand to Researchers in processing the fuzzy data. Researchers are exploring the fuzzy logic for the diagnosis process of machinery. E.g. In fuzzy based fault detection of induction motor, the conditions based on stator and phase amplitude features of stator currents are exploited in developing the decision data. This method has been preferred, because fuzzy logic has proven its ability in mimicking human decision process [27] in midst of uncertainty and vagueness in terms used. The stator voltage and phase condition monitoring problem has typically been solved as portrayed in [28-29].

The appropriate fault diagnosis becomes a subtle task with traditional methods. This is because the modern textile machineries engross advanced technologies and their hardware and software architectures tend to be very complex. Conventional computing technique is intolerant to imprecision, uncertainty, partial truth, and approximation. This stipulates the necessity of intelligent methodology for both flexible and easy implementation of Fault Detection followed by their Diagnosis. Fuzzy Logic supports processing the information both quantitative and qualitative in nature taking little closer to human way of decision building in many fields including the Textile Industry.

1.4 Research Aim and Objectives

With evolutions of machines the fault detection followed by its diagnosis is day by day becoming a complex affair. Every class of Industry has its own machinery setup and faults associated with its operating mechanisms. Textile manufacturing process runs through variety of mechanisms and it
involves variety of machineries. As in other Industries the Textile Industry is also bound to face the problems arising due to faults occurring at different levels of machine operations. Faults need to be detected in time, classified properly and tackled accordingly based on the fanatical diagnosis made. In majority of fault correcting algorithms human intervention is inevitable. This is one of the motivating factors of exploring underlying capabilities of Fuzzy Logic in the field of Textile Industrial Fault Detection and Diagnosis process consolidated through intervention of human decision-making.

The task of fault diagnosis in Textile Industry can be formulated as ‘combinational multiple objective- multistage process problem’ associated with constraints and heterogeneous data. This gives rise to legion of diagnosis algorithms leading to no universally accepted optimal solution. In practice, however fuzzy logic approach is proven to be promising in finding compromised solutions in different applications. The information about the target machinery liable to be faulty exists in two the forms-

1. Numerical information derived from mathematical model (Specifications of machines and test point signals).
2. Diagnosis strategies represented in the linguistic form. This is normally given in the vague terms that exist at several levels. Such vague terms arise due to imprecise information or complexity of interdependencies between different parameters of a system (parameters or variables of a machine under consideration or parameters deciding the quality of cloth).

The fault detection and its sensible diagnosis followed by corrective actions engrosses the human intertwining at every level in the Textile Industry and it turned out to be a good target problem for Fuzzy Logic. In most of the cases the possibility of fault occurrence described is imprecise and ill defined. The fault diagnostic algorithms appear to be cut-and-try procedures going through iterations taking pause at different level of decisions. During fault diagnosis the Machine Maintenance Engineer has to take some clever technical
decisions. The fault diagnosis problems are thus knowledge based on one hand and rule based on the other hand. The knowledge involved is largely uncertain and in the form of thumb rules expressed in the linguistic form. This provides a challenging opportunity to apply the concepts and ideas of Fuzzy Set Theory and Fuzzy Logic in the Fault Corrective actions based on the fault diagnosis made under uncertain environment. Moreover, human factors involved in the fault parameter selection and its evaluation makes the Fault Diagnosis in the Textile Industry a natural target for application of Fuzzy Logic.

The research objectives of present research were to develop and integrate the Fuzzy Inference System Techniques for obtaining better detection, classification, diagnosis and providing information on corrective action upon occurrence of faults in machinery of Textile Industry. The objectives of research work undertaken were as follows-

- To survey textile machines like air jet and projectile looms and study its functional mechanism.
- In order to identify the most detrimental faults in textile machines a comprehensive survey was conducted to identify the most frequently occurring faults and classify these faults under appropriate category.
- To improve the utilization of information resources to higher extents from non technical Operator having long experience and besides Technical Expert.
- To take brief review of the different techniques of fault detection and diagnosis.
- To seek the feasibility of fuzzy methodology in the detection and diagnosis process of faults occurring in the Textile Industry.
- To opt for those faults accountable to fuzzy logical detection and diagnosis based on the fault liable data gathered during monitoring process.
To design and develop fuzzy based diagnosis and suggest fault corrective course of action.

To establish noise susceptible communication link between Fault Interface System and Fuzzy Inference Process.

To set up the Fault Monitoring Systems that could assemble the valuable information about the fault and the location of fault prone machine and engender a kind of guidelines for an Operator in the linguistic form via the apparatus of Approximate Reasoning so as to accomplish better comfort in understanding and attending faults who otherwise has to face tangling situation due to lower level of technical skills.

To reduce the communication gap between the machinery ‘Operator’ and ‘Technical Expert’ with fuzzy logical approach.

To develop the Fuzzy based Fault Detection System that could detect and identify the nature of fault and spot the fault location in textile machinery.

To determine strategies and policies to tackle the fault occurred by means of underlying expressive power of fuzzy logic language in hope to improve the maintenance schedule by which the maintenance costs can be reduced and the machinery operating risk can be minimized.

1.5 Possible benefits and Novelty of approach

Fuzzy systems are more robust than conventional counterpart, because they cover a much wider range of operating conditions than conventional systems can, and operate normally even in the midst of noise and disturbances. Developing a Fuzzy System is cheaper than developing model-based or other systems performing the similar task. Fuzzy Systems are customizable, since it is easier to understand and modify their rule base, which not only explores human operator's strategy, but are expressible in natural linguistic terms.
It is easy to learn how Fuzzy Systems operate and how to design and apply them to a tangible application. Fuzzy techniques have received much attention due to their fast and robust implementation, capacity to embed apriori knowledge, to imitated nonlinear mappings, and abilities of generalization. Thus, fuzzy logic techniques are now being practiced as a powerful modeling and decision-making tool in the Fault Detection and Isolation (FDI) by Research Community, sometimes as an Add-On solution to traditional techniques such as non-linear and robust observers, parity space methods and hypothesis-testing theory to enhance their performance. To circumvent conventional precision modeling problems more abstract models with qualitative approaches based on the theory of Fuzzy Logic can be a good alternative.

Fuzzy Systems accept numeric inputs from the outside world and convert them into linguistic values that can be manipulated by using fuzzy logic operations in association with linguistic if-then rules prearranged by human operators. The linguistic outputs, the result of the fuzzy logic operation are converted into numeric outputs, which are then conveyed to the outside world [22, 25]. In the field of control system, many complex plants are difficult to deal with by the conventional approaches because of their nonlinear, time-varying behavior and imprecise information furnished by sensor system. Nevertheless, human operators can handle these complex plants by their practical experience. They can easily muddle through with imprecise system states, set of imprecise states and set of imprecise linguistic if-then rules. The Fuzzy Systems based on theory of Fuzzy Set and Fuzzy Logic can be used to deal with such complex systems [21, 25].

Fuzzy Logic endow with a scheme of reducing and explaining system complexity [11]. It deals with system uncertainties and ambiguities in a way that mimics human reasoning. Fuzzy logic allows the membership of a variable within a group to be estimated with a prescribed degree of uncertainty. In this
way, the application of Fuzzy Logic to machinery fault diagnosis allows the membership of dynamic signal frequency spectra from an unknown source to be determined with respect to a set of spectra representing particular faults.

The entire research work has been centered on the exploiting the Fuzzy Logic based modus operandi as a machinery fault diagnostic technique. Its ability to classify and identify machinery faults demonstrated the considerable potential in employing the Fuzzy Logic in Fault Detection followed by its Diagnosis in the Textile Industry. An attempt has been made to comprehend the procedure for arriving at this objective. The optimum limits were found manually in this study, but this process could also be automated easily. Using fuzzy membership functions that are similar in shape to the distribution of data within the dynamic signal would be relatively easy to implement. This has been effectively customized to exploit in a wide variety of applications and thereby greatly enhance the overall performance of system approach in Textile Industrial Field not an exception.

1.6 Outline of Present Research Work

With the hope of greater automation in machines the conscientiousness of Electronics went on elevating. This lead to the introduction of Mechatronics Technology and practiced in varieties of Industrial Fields including the Textile Industry. And this is how the “weaving machine” took the place of the term “loom”, indicating the significant role of Electronics in Mechanical Systems. Thus comprehensive survey of Textile Industry helped to form the very first aim of present research the understanding of the different machines and their operational mechanism in textile industry in addition to the different kind of fault that are likely to hamper the overall performance of machines of Textile Industry.

Weaving machines are classified into four groups according to their weft insertion systems as Shuttle, Projectile, Rapier and Jet (i.e. air and water jet)
looms. Of these groups, the shuttle and projectile weft insertion systems have reached the term of their economic life, because of their low weaving velocity. The water jet weft insertion system does not have a wide application in practice, as it is only suitable for yarns made of hydrophobic fiber. Rapier and air jet weft insertion systems are commonly used for almost all kinds of fibers and yarns. When air jet and rapier weft insertion systems are compared, it is apparent that the rapier system has a lower velocity than air jet systems. The air jet weaving system is commonly preferred due to its high production speed. Especially air jet looms have been spread over to weaving mills widely and rapidly because of its great return in terms of productivity.

The weaving machines incorporated with diversified sections like Motors Status Detection Unit, Oil Tank Unit for Lubrication, Emergency Fault Detection Unit and so on. The environmental conditions like temperature and humidity are also contribute significantly towards good productivity and better quality of Textile. Our investigation has been founded on these core objectives to design and develop different sub-modules that gather the parameter data at central location from the every sub-section of the Textile Industry and analyze it with standard obligatory values to create a favorable environment and/or maintain the machinery status in good condition by fault detection followed by their diagnosis. It was intended to implement the reliable communication network projected to work with the good efficiency and at the minimal cost affordable by the smaller textile industry and sustain the communication in midst of noise. The various sub modules have been interconnected to the central station by means of the Controller Area Network (CAN) bus to form an entire sensing network of the Textile Industry. The central unit has been made to collect the data on different machine parameters and send them to the PC to watch and view for factual analysis and storage for later reference. This formed the first phase of research that was indented to develop the communication network help supervisor and operator to monitor the different sections of the
textile from central location. After comprehensive study of fault occurrence in Textile Industry the faults feasible to deal with fuzzy logically were chosen that included the Motor Status, Environmental Temperature and Humidity, Oil Tank Level and Pressure. Based on these variables or parameters Fuzzy Decision System developed was intended to report the overall Health condition of Machine under supervision to the Department of Monitor and Control.

The second phase of the research work was to investigate the feasibility of employing underlying concepts of fuzzy logic in the process of machine fault detection and diagnosis. Soft Computing is a collection of methodologies, which aims to exploit tolerance for imprecision, uncertainty, partial truth, and approximation to achieve better tractability, robustness and low solution cost. Human brain is capable of processing the information qualitatively at reasonable low cost and high efficiency. The objective of soft computing is to make computer as soft as the human brain capable of carrying out both quantitative and qualitative computing. Along this path, Fuzzy Logic has been developed to handle qualitative information and hence it is called Fuzzy Computing. The benefit of Fuzzy Logic is that it exhibits the nature of human way of data processing and makes the decision or judgment using linguistic interpretation. Additionally, the control rules and inference logic based on the perception, experience and suggestion of a human expert can be encoded in the meaningful way to avoid mathematical modeling of the problem. The faults in Textile Machines are uncertain and non-linearly occur. Sometimes the signal from sensors is of caricature nature. There is need of identifying likely instant of fault occurrence based on the trends received from sensor signal. The inability of proper prediction makes the fault detection uncertain. After considering these issues extensively we decided to practice the Fuzzy Methodology as a better alternative to deal with Textile Industrial Fault Detection and Diagnosis more efficiently and economically. In the present work Industrial Machine Fault Detection and Diagnosis System has been
designed and developed for the realization of the Fuzzy based optimistic fault diagnosis approach with emphasize given on achieving the ease of tackling the machine faults by unskilled Operator and lower the overall maintenance cost.

The *Third phase* of research work was intended to develop the Simulation Model for Fault Detection and Diagnosis Process. To drive the simulation Models with real-time data the Sensor System and Data Acquisition Cards were designed and developed for Machine Health deciding parameters. Based on the study carried out during the second phase software pertaining to Fault Detection and Fuzzy Diagnosis has been designed and developed in MATLAB™ comprising Fuzzy Logic Modules that help analyzing data from sensor system pertaining to specific fault or environmental condition and form decisions for instigating diagnosis process. Multiple Fault Detection Modules for different sections in Textile Industry have been designed in MATLAB with ability to generate report and comment for a particular fault under observation. The software helps the Operator, Maintenance Engineer and also Supervisor during either occurrence of fault or process of periodical maintenance cycle. For ease the Graphical User Interface (GUI) frames have been created to display the Fault Type, Location of Fault and elucidation for circumventing the fault. All Fuzzy Modules before yielding acceptable outcomes were forced to go through vigorous tuning iterations with regard to membership functions and fuzzy rules and defuzzification methods.

Implementation of the Fuzzy Monitoring and Fuzzy Diagnosis schemes into the target PIC microcontroller formed the *fourth and final phase* of the research work. The MATLAB™ based Fault Detection and Fuzzy Diagnosis software designed, developed and testified in the third phase was considered as the basis for the embedded fault detection tactics and fault diagnosis policies. PIC18F2480 has been used as a target microcontroller due to reasonably good computational performance and economical cost. MPLAB software environment from Microchip was used for development and downloading. The
two popular fuzzy reasoning methods devised by the Mamdani and Sugeno based on different fuzzy inference implication for consequent premise of fuzzy if-then rules are available with MATLAB. Throughout implementation of Fault Monitoring and Fuzzy Diagnosis process Mamdani’s Method has been employed. The rule base and database were incorporated into the PIC microcontroller of the central unit that generates the fuzzy decisions to be displayed for an Operator or Machine Engineer to understand. The Embedded Fuzzy Modules were enforced to run through tuning iterations and tested before being validated based on their performance under different conditions.

1.7 Outline of Thesis

The entire research work is presented in the thesis in five chapters as follows-

Chapter 1 highlights the introduction to the different types of faults in the industries; basically from textile industry. It also includes the survey of different industries studied according maintenance cost and different categories of faults like mechanical, electrical and electronics hardware faults. It introduces Fuzzy logic as a powerful tool for reducing fault diagnosis system complexity. Literature survey includes the literature on past research on fault and fault detection, machinery fault diagnosis, condition monitoring, reliability, maintenance, Artificial Intelligence and fuzzy techniques.

Chapter 2 gives the brief outline of the different machines used in textile industry. It describes the basics of manufacturing processes carried out in the weaving and spinning sections. It focuses on the different fault collection and diagnosis models and methodologies along with the machine maintenance methods. The chapter concludes with the description of sensing technologies those can be useful in fault collection process.

The fuzzy inference system and fuzzy modeling of the different fault collection and diagnosis systems are incorporated in Chapter 3. It gives the
details of the FIS design of the motor fault determination, oil tank determination, machine environment condition determination and emergency fault determination. It includes the design of simulation models useful for the understanding of the system.

Chapter 4 depicts the details of the hardware design of the fault collection units. It explains the aspects of fault collection subsystems like sensor selection, signal conditioning units, methods useful for machine parameter data collection and the design of central unit. It also specify the software algorithms to identify the fault condition and to provide the remedial solution. The MATLAB based GUI for the operator ease is also included in this chapter.

The conclusive Chapter 5 gives the summery of the work done and the discussions on the simulation results obtained from the designed FIS and fuzzy models. The real time data results are also comprised in this chapter. The final part of the chapter includes the convincing outcomes of the work done along with the future work that can be carried out in upcoming years.

1.8 References


