3.1 Modeling Fault Detection and Fuzzy Diagnosis

Machine Fault Diagnosis in general involves the integrated system architecture comprising following various modules is shown in Fig. 3.1.

1. **Sensor Suite** and suitable **Sensing Strategies** gather and process the data pertaining to the critical process variables and parameters.
2. **Analysis Module** in relation to failure modes and effects determines and sets priorities according to the frequency of occurrence and their criticality and severity of possible failure modes followed by cataloging systematically the Effect-Root Cause relationships.
3. An **Operating Mode Identification Routine** determines the current operational status of the system and correlate fault-mode characteristics with operating conditions.
4. A **Feature Extractor Module** selects and extracts features or fault occurrence trend from raw data to be explored by the **Fuzzy Diagnostic Module**.
5. A **Fuzzy Diagnostic Module** assesses through the online observations the current status of machine components found to be at the verge of critical condition.
6. The final module - the **Maintenance Scheduler** of the integrated architecture schedules the maintenance operations without affecting adversely the overall system functionalities of which the machine in question being one of the constituent elements.

The machine fault detection includes the modules to determine the Status of Motor, level standing of the Lubricant Oil Tank, the Environmental Conditions besides the Electronic Dobby and Logic Card. The sensor system incorporated with pick up units for Motor Current, Oil tank pressure and level, Environmental temperature and humidity forms the crucial interface of machine fault detection process.

### 3.2 Motor Status Detection

The induction motor has been widely used motor for industry it continues with increasing applications. This is chiefly due to its low cost, reasonably small size, ruggedness, low maintenance, and operation on easily available power supply. On the other hand, the spreading of Power Electronics

---

**Fig. 3.2: Motor Fault Tree**

```
Motor failure
  /\                               /
 Local Powerline Failure Gear Box Failure Internal Motor Failure
  /                             /                          /
 Gear Slip Wear on Gears
```
and the development of modern control techniques has made the induction machine a good solution for very never kind of applications [1]. Textile industry is not the exception to use induction motors. Fault in motor could be either mechanical or electrical in nature. They seem to be independent, but in some occasions one fault may be the root cause of other. The possible fault tree is shown in Fig.3.2.

The major intricacy is the lack of an accurate model that describes a fault in the motor. Moreover, experienced Engineers are often called upon to interpret measured and/or observed data that are frequently inconclusive or unconvincing. A Fuzzy Logic approach help diagnose induction motor faults under such jittery situations. In fact, Fuzzy Logic is reminiscent of human thinking process and natural language enabling decisions to be made based on vague information. Therefore, fuzzy logic technique can adequately be extended to the Induction Motor Fault Detection and Diagnosis. The motor condition is described using linguistic terms like ‘good’, ‘bad’, ‘overload’, ‘performance declined’ etc. Thus health interpretation of induction motor turns out to be a Fuzzy Concepts [2].

Fuzzy subsets can be assigned to describe the stator current amplitudes by means of corresponding membership functions. A knowledge base pertaining to situations liable for faults in the motor comprising rule base and data base can be built to activate the fuzzy inference. The induction motor condition can thus be diagnosed using an apparatus of fuzzy inference.

![Fig. 3.3: Motor Condition Status](image-url)
Induction motor under consideration is of 2-KW, 220/380 V, 15/8.6 A, 50-Hz, 4 pole, \( \Delta \) connected squirrel cage type.

The judgment of induction motor condition made based on fuzzy inference is capable of better diagnosis as it shares the human’s knowledge expressed in vague terms like "somewhat secure", "little overloaded" with computing abilities of computer etc. Such linguistic input prepositions can be directly expressed by Fuzzy System. The structure of Fuzzy Monitoring and Diagnosis is shown in Fig. 3.3 and Fig. 3.4. The stator current signal reciprocates the promising information relating to fault.

Fuzzy systems rely on a set of rules. These rules allow the input to be fuzzy permitting the words to describe the fault conditions bringing a sort of robustness in information processing. Motor being an electro-mechanical system, the applied voltage, current drawn by the motor and internal temperature play a major role in reciprocating the faults. In the present study the motor phase currents have been monitored and based on the subsequent trend in the current values diagnosis of motor status has been judged. For Fault

---

![Fig. 3.4: Motor Condition determination Setup Layout](image-url)
Detection and Diagnosis of Induction Motor stator current amplitudes viz. $I_a$, $I_b$, and $I_c$ have been considered as the input variables to the fuzzy system. The motor condition, $M_c$, has been chosen as the output variable.

We have defined the fuzzy subsets $I_a^r$, $I_b^r$ and $I_c^r$ for input variables going to the Fuzzy Systems and $M_c^r$ for output variable as follows:

$$I_a^r = \mu_a(I_a)/I_a^r, \forall I_a^r \in I_a$$

$$I_b^r = \mu_b(I_b)/I_b^r, \forall I_b^r \in I_b$$

$$I_c^r = \mu_c(I_c)/I_c^r, \forall I_c^r \in I_c$$

$$M_c^r = \mu_{M_c}(m_c)/m_c^r, \forall m_c^r \in M_c$$

Where $I_a^r$, $I_b^r$, $I_c^r$ and $M_c^r$ are elements of the discrete Universe of Discourse (UoD) $I_a$, $I_b$, $I_c$ and $M_c$.

Fuzzy logic works with linguistic variables whose values are words or sentences in a natural or artificial language. This provides a means of systematic manipulation of vague and imprecise information. The term set (T) is a collection of linguistic values assigned to linguistic variable. The term sets used for stator current and motor condition are as follows:

$T(I_a, I_b, I_c) = \{ \text{Zero (Z)}, \text{Small (S)}, \text{Medium (M)}, \text{Big (B)}, \text{Very Big (VB)} \}$

$T(M_c) = \{ \text{Open_phase, Damage, Critically_overloaded, Overloaded, Good } \}$

The optimized rule base has been developed so as to encompass all possible healthy and faulty conditions of the motor.

### 3.2.1 FIS Design for Motor Status Detection

Fuzzy Inference System (FIS) for Motor Status Detection has been created using Fuzzy Tool Box of MATLAB. It forms the major functional block of Fuzzy Monitoring and Fuzzy Fault Detection and Diagnosis. It is shown in Fig.3.5.
Motor stator current amplitudes viz. $I_a$, $I_b$, and $I_c$ are the input variables to the fuzzy system and motor status condition, $M_c$, is the output variable. The input stator motor currents are portioned into five fuzzy subsets labeled with linguistic values as Zero (Z), Small (S), Medium (M), Big (B), Very Big (VB). In a same way the output variable- the Motor_condition (Stator condition) is interpreted as linguistic variable with linguistic values as Open_phase, Damage, Critically_overloaded, Overloaded and Good. Membership functions are constructed by observing the data set and the trends in the stator currents that are likely to cause the faults in the motor. For the sake of initial design success we did relied on the triangular membership functions.

The membership functions for output and input variables are shown in Fig.3.6 and Fig.3.7 respectively. For actual current ranges the motor specification has been referred to and used in the creation of FIS.
3.2.2 Rule Based Inference

This is the critical part of any Fuzzy System. After keen study of motor and fault prone situation we could identify 23 situations where motor condition is unhealthy. The inference rules can be classified into six distinct categories based on consequent parts. These situations were framed in the form of fuzzy If-Then rules enlisted as follows.

Linguistic variable Open_phase indicates the stator current from any or all three phases are zero. It may occur due to absence of phase. The first rule is for this fault condition.

Rule (1): IF \( I_a \) is Z or \( I_b \) is Z or \( I_c \) is Z THEN \( M_c \) is Open_phase

After transient time all the stator current \( I_a, I_b, I_c \) are in normal range i.e. Small hence the motor is operate in normal condition. Linguistic variable
used for normal condition is *Good*. The rule number five is for *Good* condition of Motor.

Rule (2): IF $I_a$ is S and $I_b$ is S and $I_c$ is S THEN $M_c$ is *Good*

If the load on induction motor increases, then the current also increases. When stator current $I_a$, $I_b$ or $I_c$ are in Medium range then the Motor condition is Over load, for this the next seven rules are defined.

Rule (3): IF $I_a$ is S and $I_b$ is S and $I_c$ is M THEN $M_c$ is *Over Load*

Rule (4): IF $I_a$ is S and $I_b$ is M and $I_c$ is S THEN $M_c$ is *Over Load*

Rule (5): IF $I_a$ is S and $I_b$ is M and $I_c$ is M THEN $M_c$ is *Over Load*

Rule (6): IF $I_a$ is M and $I_b$ is S and $I_c$ is S THEN $M_c$ is *Over Load*

Rule (7): IF $I_a$ is M and $I_b$ is S and $I_c$ is M THEN $M_c$ is *Over Load*

Rule (8): IF $I_a$ is M and $I_b$ is M and $I_c$ is S THEN $M_c$ is *Over Load*

Rule (9): IF $I_a$ is M and $I_b$ is M and $I_c$ is M THEN $M_c$ is *Over Load*

The amount of current increases in range Big, this stage can be defined as *Critically Overload*. The next rules from 10 to 21 are defined for *Critically Overload* condition.

Rule (10): IF $I_a$ is B and $I_b$ is S and $I_c$ is S THEN $M_c$ is *Critically Overload*

Rule (11): IF $I_a$ is B and $I_b$ is S and $I_c$ is M THEN $M_c$ is *Critically Overload*

Rule (12): IF $I_a$ is B and $I_b$ is M and $I_c$ is S THEN $M_c$ is *Critically Overload*

Rule (13): IF $I_a$ is B and $I_b$ is M and $I_c$ is M THEN $M_c$ is *Critically Overload*

Rule (14): IF $I_a$ is S and $I_b$ is B and $I_c$ is S THEN $M_c$ is *Critically Overload*

Rule (15): IF $I_a$ is S and $I_b$ is B and $I_c$ is M THEN $M_c$ is *Critically Overload*

Rule (16): IF $I_a$ is M and $I_b$ is B and $I_c$ is S THEN $M_c$ is *Critically Overload*

Rule (17): IF $I_a$ is M and $I_b$ is B and $I_c$ is M THEN $M_c$ is *Critically Overload*
Rule (18): IF \( I_a \) is S and \( I_b \) is S and \( I_c \) is B THEN \( M_c \) is Critically\_Overload

Rule (19): IF \( I_a \) is S and \( I_b \) is M and \( I_c \) is B THEN \( M_c \) is Critically\_Overload

Rule (20): IF \( I_a \) is M and \( I_b \) is S and \( I_c \) is B THEN \( M_c \) is Critically\_Overload

Rule (21): IF \( I_a \) is M and \( I_b \) is M and \( I_c \) is B THEN \( M_c \) is Critically\_Overload

Rule (22): IF \( I_a \) is B and \( I_b \) is B and \( I_c \) is B THEN \( M_c \) is Critically\_Overload

The last group of rules is for Damage condition of motor. If the current flow is very large current (VB) then the motor is in Damage state. The rules for this condition are defined from rule 23.

Rule (23): IF \( I_a \) is VB or \( I_b \) is Not VB or \( I_c \) is Not VB THEN \( M_c \) is Damage

The set of 23 rules after careful study has been put in compact logical form as shown in table 3.1.

<table>
<thead>
<tr>
<th>Table 3.1: Rule base in Logical form</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Motor Stator Current</strong> (( I_{a/b/c} ))</td>
</tr>
<tr>
<td><strong>IF</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Any or All</td>
</tr>
<tr>
<td>Z</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>0</td>
</tr>
</tbody>
</table>

‘1’ = Condition applies to phase/s under consideration
‘0’ = Condition don’t exists on phase/s under consideration
‘x’ = Don’t care condition for other two phases

After careful observations of 23 fuzzy rules we found that the number of rules can be to only 5 rules enlisted as follows-

Rule (1): If \( I_a \) is Z or \( I_b \) is Z or \( I_c \) is Z THEN Open\_phase (1)

Rule (2): If \( I_a \) is B or \( I_b \) is B or \( I_c \) is B THEN Critically\_Overload (0.9)

Rule (3): If \( I_a \) is M or \( I_b \) is M or \( I_c \) is M THEN Over\_Load (0.8)
Rule (4): If $I_a$ is S or $I_b$ is S or $I_c$ is S THEN Good (0.7)

Rule (5): If $I_a$ is VB or $I_b$ is VB or $I_c$ is VB THEN Damage (1)

By Inference input conditions of stator currents are mapped with consequential output motor health conditions and output on the health of the motor at any instant of time is derived. It is followed by the process of Defuzzification for computing crisp indication of motor health condition based on the fuzzy output generated by rule firing process of Fuzzy Inference. There are many types of defuzzification methods available. But we have employed the Center of Area (COA) method for defuzzification. Despite its complexity it is more popularly used because, if the areas of two or more contributing rules overlap, the overlapping area is counted only once.

If any incipient faults or slight voltage unbalance occurs, then the output of the FIS generates the output corresponding to Damage. Immediately the fault data and the current are stored in a file for analysis purpose with time as long as fault persists. For the severe faults such as open phase, open coil, single line to ground short and line to line short, the Fuzzy Inference output will be seriously damaged. In this state the machine should not be allowed to operate any further.

Whenever the FIS output indicates condition ‘Damaged’, the machine gets isolated from the supply and stores the instantaneous fault data. The front panel of the monitoring system displays the possible cause of damaged state of the motor.

Stator currents were measured and their amplitudes derived. These amplitudes were transferred over to respective Discourse of Universe as inputs. The Fuzzy Logic inference engine evaluates the inputs using the knowledge base and then diagnoses the stator condition. In this final step, the fuzzy actions are reconverted to crisp value by “center of area” method [3]. First each affected output membership function is cut at the strength indicated by the previous max-rule, next the gravity center of the possible distribution is computed is equivalent to the crisp output value.
For illustration, Fuzzy Inference of different stator currents is shown, for which the induction motor stator condition is good, Over_Load, Critically_Overload, Damaged, or Open_phase. As it could be noticed, fuzzy rules are solicited, according to stator current amplitudes, leading to the determination of the motor condition.

### 3.2.3 Development of Simulation Set up

About 70% of mechanism are directly or indirectly depends on the proper function of Motors used in the Textile Industry. In other words Motors play significantly a vital role in the Textile Industry and therefore prime

![Simulink Model for Motor Condition determination](image)
attentions are being focused on the health conditions of Motors. We have developed a fuzzy based simulation model using Simulink Blockset of MATLAB for determining the health of motor under supervision. The complete set up of Fuzzy based Fault Detection and Diagnosis for Induction Motor has been built around the Fuzzy Inference System designed in Simulink for detection of motor health condition and it is shown in Fig. 3.8. The built-in blockset of Induction motor has been employed for the purpose of study. Simulink model is categorized into different categories like Induction Motor Drive with Power Supply, FIS, RMS to DC conversion and Fault creation. Three phase voltage supply is applied to induction motor. The induction Motor parameters are specified in the specific block like speed, torque as indicated in figure. Induction Motor Drive block includes the three phase induction motor in same block.

The stator current of the induction motor is in AC form, it is necessary to convert it into DC. Therefore next block is RMS to DC conversion, which converts the RMS value into DC form. This block measures the root means square value of instantaneous current signal connected to the input of the block. The RMS value is calculated over a running window of one cycle of the specified fundamental frequency.

Fault creation block is for simulating of faults. Different faults like open phase, unbalance of input voltage are artificially generated in this block. Different blocks like Sum, Product, Step input and Constant are used in fault creation.

The block FIS for Motor implements a fuzzy inference system (FIS) in Simulink. Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The in our case is Stator current from each phase and output is condition of motor in linguistic form using fuzzy logic. The output is having range from 0 to 1 which is stored as variable M_COND in workspace and display on scope as well as its value on Display block. The mapping then provides a basis from which decisions can be made,
or patterns discerned. The process of fuzzy inference involves all of the pieces that are Membership Functions, Logical Operations, and If-Then Rules.

The motor condition may be good, damaged, overloaded, critically overloaded or open phase. The standard test input signals to the input of Stator current $I_a$, $I_b$, $I_c$ are applied to fuzzy logic controller for observing the motor condition output.

### 3.2.4 Rule Viewer

MATLAB Fuzzy Tool facilitates the insight to Fuzzy Inference process vide the Rule Viewer option on FIS Edit Menu. This greatly helps the FIS development phase for proper designing of Fuzzy Sets, Fuzzy Rules and overall performance of FIS in terms of output targeted for all possible range of inputs. Fig. 3.9 depicts the whole process of Fuzzy Inference for the rule (1) to (8) under activation. The present stator currents are $I_a = 4.74A$, $I_b = 4.65A$, $I_c = 4.80A$ which are falling in fuzzy set “S”. The fuzzy inferred Motor_condition...
value comes to be 0.789. This indicates the motor is in ‘Good’ Condition thereby matching the anticipated on time by common sense.

![Rule viewer for Phase open](image)

**Fig. 3.10: Rule viewer for Phase open**

<table>
<thead>
<tr>
<th>Rule Activated</th>
<th>Present Stator Currents $I_a$ (A)</th>
<th>$I_b$ (A)</th>
<th>$I_c$ (A)</th>
<th>Inferred Motor Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 to 8</td>
<td>4.74</td>
<td>4.65</td>
<td>4.8</td>
<td>0.789</td>
</tr>
<tr>
<td>21</td>
<td>13.60</td>
<td>10.8</td>
<td>0</td>
<td>0.06</td>
</tr>
<tr>
<td>2, 4, 6, 8</td>
<td>4.74</td>
<td>4.65</td>
<td>20.1</td>
<td>0.695</td>
</tr>
</tbody>
</table>

**Table 3.2: Table of Results for Motor Health**
Similarly Fig. 3.10 depicts the process of Fuzzy Inference for the rule (21) under firing. The present stator currents are $I_a = 13.60\, \text{A}$, $I_b = 10.80\, \text{A}$, $I_c = 0\, \text{A}$ which are falling in fuzzy set “S”, “S” and “Z” respectively. The fuzzy

Fig. 3.11: Rule viewer for Input Unbalanced Input Voltage

Fig. 3.12: Rule viewer for Good Condition using five rules
inferred Motor\_condition value drops to be 0.0618 indicating that the motor is in Open Phase Condition.

In a same manner with $I_a = 4.74\, A$, $I_b = 4.65\, A$, $I_c = 20.1\, A$ the fuzzy inferred Motor\_condition equals $0.695$ showing a status of overloaded. Rule viewer for input unbalanced input voltage is shown in Fig. 3.11.

![Fig. 3.13: Rule viewer for Phase open using five rules](image1)

![Fig. 3.14: Rule viewer for Overload using five rules](image2)

The Fig. 3.12, 3.13, 3.14 are the Rule viewer for Good condition, Open phase and overload respectively using 5 rules. For Fig. 3.12, it is rule (3) and
that is solicited, in fact \( I_a = 4.52 \text{A} \), \( I_b = 3.92 \text{A} \) and \( I_c = 4.52 \text{A} \) are small “S”. The motor is in this case supposed to be good condition (Motor_condition = 1).

### 3.2.5 Surface Viewer

The surface viewer depicts the dependencies of output on the input stator current as illustrated in fig. 3.15. The surface viewer also shows the behavior of the system. The Good Condition of Motor is only when all Stator currents are in Small range.

![Surface View of Motor Condition FIS for 23 rules](image)

**Fig. 3.15: Surface View of Motor Condition FIS for 23 rules**

Fig. 3.16 shows the Surface viewer of Motor Condition for five Rule base. Previously 23 rules were defined and studied for Motor condition. Here the rules are reduced and now only five rules are selected after careful study of revision of rule base for FIS of Motor condition. Different conditions were generated manually in the rule view and for simultaneous evaluation has been carried out and analyzed. The system behaviour is little more dynamic as compared to system with five rules.
3.3 Environment Condition Determination

The environmental conditions with respect to temperature and humidity play very important part in the manufacturing process of textile industry. The properties with respect to dimensions, weight, tensile strength, elastic recovery, electrical resistance, rigidity etc. of all textile fiber including natural and synthetic are influenced by moisture regain expressed in percentage. Many properties of textile materials vary considerably with moisture regain, which in turn affected by the ambient Relative Humidity (RH) and Temperature. If a dry textile material is placed in a room with a particular set of ambient environmental conditions, it absorbs moisture and in course of time attains equilibrium. Some physical properties of textile materials which are affected by Relative Humidity with % humidity-

1. The strength of cotton goes up
2. The strength of viscose goes down
3. The fiber elongates
4. The tendency for generation of static electricity due to friction decreases
5. The tendency of the fibers to stick together increases

![Surface View of Motor Condition FIS for five rules](image)
Temperature alone does not have a great effect on the fibers. However the temperature dictates the amount of moisture the air will hold in suspension and, therefore, temperature and humidity must be considered simultaneously while optimizing the environmental conditions in the textile mills [4]. **Cooling and Humidification** is a process involving reduction in Dry Bulb Temperature and increase in specific humidity. **Heating and Dehumidification** is a process where there is an increase in Dry Bulb Temperature and reduction in specific humidity. **Heating and Humidification** is the process where there is an increase in both Dry Bulb Temperature and specific humidity.

### 3.3.1 Air Conditioning Process for the Textile Industry

When air is drawn in and passed through the Air Washer, it gets saturated adiabatically. Since it is not saturated 100%, the dry bulb temperature of the saturated air will be $1^\circ C$ greater than Wet Bulb Temperature. When this air is admitted into the conditioned space, it gets heated due to the heat load of the room. During this heating process the air does not lose or gain any moisture as latent heat load is absent. The air displaces an equal amount of air in the room which is pushed outside the room.

If we know the heat load of the room, we can easily calculate the rate of flow of air ($G$), which is the air circulation rate necessary to give the required relative humidity as given by equation (3.1)

$$G = H(h_2 - h_1)$$  \hspace{1cm} (3.1)

Where,

- $G$ = Mass flow rate of dry air, Kg/h
- $H$ = Total heat of air, Kcal/h
- $h_2$ = Enthalpy of supply air, Kcal/Kg
- $h_1$ = Enthalpy of outgoing air, Kcal/Kg
The air circulation rate is generally expressed in cubic meters per hour and not in terms of mass flow rate. \((h_2-h_1)\) can be calculated from the initial and final temperatures. Therefore

\[
H = \left(\frac{Q}{V}\right) \times C_p \times (DB_2 - DB_1)
\]

Where,

- \(Q\) = Rate of air flow in \(m^3/h\)
- \(C_p\) = Specific heat of air
- \(V\) = Specific volume of air, \(m^3/kg\)
- \(DB_1\) = Supply air Dry Bulb Temperature in \(^\circ\)C
- \(DB_2\) = Leaving air Dry Bulb Temperature in \(^\circ\)C

However in practice, the Air Washer does not continuously supply air of 100\% Relative Humidity. It is considered satisfactory, if the difference between Dry Bulb Temperature and Wet Bulb Temperature of air after the Air Washer is 1\(^\circ\)C. The equation (3.2) can be used for practical purposes.

\[
(DB_2 - DB_1) = \left(\frac{3.30 H}{Q}\right) - 0.52
\]  
(3.2)

Once the relative humidity to be maintained is decided, the quantity \((DB_2 - DB_1)\) is fixed. In other words, once the inside relative humidity is fixed the minimum dry bulb temperature in the condition space is determined by the Wet Bulb Temperature of the outside air. It is not possible to go below this Dry Bulb Temperature unless refrigeration is used.

**Need of refrigeration**

In case the Wet Bulb Temperature of outside temp is 35 degrees and if the % Relative Humidity to be maintained inside the mill is 60%, then Dry Bulb Temperature of the conditioned space should be 43.5 degrees. It is not possible to reduce this temperature as long as Relative Humidity is to be maintained around 60\%. Under this circumstance, refrigeration process is required to bring down the Wet Bulb Temperature of the air inside, so that 60\% Relative Humidity can be maintained at lower Dry Bulb Temperature.
It is obvious that the mechanical behaviour of textile fiber is quite sensitive to their temperature. Besides rupture characteristics the stiffness and yielding are susceptible to the temperature variations. A correctly humidified environment guarantees an increase in productivity and, in case of adiabatic humidification, the significant cooling of the environment takes place. These conditions furthermore guarantee a decrease in atmospheric dust. Because dust and fiber in the air are reduced as water droplets increase their weight and bring them down to the floor. This further improves the conditions of the work environment and reduces the maintenance times involved in cleaning the filters. Another benefit is that the breakage of threads requires time-consuming manual interventions in the textile processing industry. When the relative humidity is below 50%, there is a reduction in the strength and elasticity of the threads. In contrast, increasing the relative humidity to about 70% reduces breakages by around 40% and increases the productivity. The atomization of water directly into the room both ensures the required relative humidity and provides adiabatic cooling due to the heat absorbed by the water when evaporating [5]. A typical application with the atomization of 100 l/h of water removes around 70 kW of heat from the air. Imprecise humidity control causes dimensional changes and makes certain processes more difficult, such as cutting the fabrics to size. Thread and fibers remain flexible help improve the process efficiency. In addition, the correct humidity level eliminates the problem of electrostatic charges, otherwise it may result into an electrical discharges and sticking of the threads. The reduction in the static electricity prevents clinging materials. However in India the climate is worm which does not demand for refrigeration.

Recommended temperature and humidity values for various textile applications are given in table 3.3[5].
### Table 3.3: Recommended temperature and humidity values

<table>
<thead>
<tr>
<th>Material</th>
<th>Application</th>
<th>Air Temperature (°C)</th>
<th>Relative Humidity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton</td>
<td>-</td>
<td>20 to 25</td>
<td>60 to 70</td>
</tr>
<tr>
<td>Wool</td>
<td>Carding/Combing</td>
<td>20 to 25</td>
<td>65 to 80</td>
</tr>
<tr>
<td></td>
<td>Ring Spinning</td>
<td>20 to 25</td>
<td>55 to 60</td>
</tr>
<tr>
<td></td>
<td>Weaving</td>
<td>22 to 25</td>
<td>55 to 65</td>
</tr>
<tr>
<td>Linen</td>
<td>Carding</td>
<td>20 to 25</td>
<td>50 to 60</td>
</tr>
<tr>
<td></td>
<td>Spinning</td>
<td>20 to 25</td>
<td>60 to 70</td>
</tr>
<tr>
<td></td>
<td>Weaving</td>
<td>20 to 25</td>
<td>70 to 75</td>
</tr>
<tr>
<td>Perlon/Nylon</td>
<td>-</td>
<td>25 to 27</td>
<td>65 to 70</td>
</tr>
<tr>
<td>Ribbons</td>
<td>-</td>
<td>22 to 25</td>
<td>70 to 75</td>
</tr>
<tr>
<td>Knitwear</td>
<td>-</td>
<td>20 to 25</td>
<td>50 to 60</td>
</tr>
<tr>
<td>Carpets</td>
<td>-</td>
<td>20 to 25</td>
<td>65 to 70</td>
</tr>
</tbody>
</table>

### Fuzzy Conditioning Approach

Moisture in atmosphere has a great impact on the physical properties of textile fibers and yarns. Relative humidity and temperature will decide the amount of moisture in the atmosphere. High relative humidity in different departments of spinning is not desirable. It will result in major problems. But on the other hand, a high degree of moisture improves the physical properties of yarn and help increase the process efficiency in the Textile Industry. Moreover it helps the yarn to attain the standard moisture regain value of the fiber. Yarns sold with lower moisture content than the standard value will result in monetary loss [6]. Therefore the aim of conditioning is to provide an economical contrivance for providing the necessary moisture in a short time in order to achieve a long lasting improvement in the product quality.

In these days there is a dramatic change in the production level of weaving and knitting machines, because of the sophisticated manufacturing techniques. Yarn quality required to run on these machines is extremely high. In order to satisfy these demands without altering the raw material, it was
decided to exploit the physical properties inherent in the cotton fibers. Cotton fiber is hygroscopic material and has the ability to absorb water in the form of steam. It is quite evident that the hygroscopic property of cotton fibers depends on the relative humidity. Higher the humidity more is the moisture absorption. The increase in the relative atmospheric humidity causes a rise in the moisture content of the cotton fiber however non-linearly. The relative humidity affects the properties of the fiber via the moisture content of the cotton fiber. The fiber strength and elasticity increase proportionately with the increase in humidity. If the water content of the cotton fiber goes high, the fiber swells, resulting in higher fiber to fiber friction in the twisted yarn structure. This positive alteration in the properties of the fiber will again have a positive effect on the strength and elasticity of the yarn and hence on the final product. Based on the past investigations on the Temperature and Relative Humidity in the textile mills some recommendation have been made are as follows-

1) Currently textile conservators tend to advise ranges for temperature (60-70 °F / 15-20 °C) and RH (40-60%) rather than single target figures. Slow, seasonal change is recommended to transition between seasonal ranges.

2) Textiles are often part of composite artifact where heterogeneous material conditions are involved with variety of process techniques. The specific homogeneous subgroups of textiles may benefit from imprecisely defined narrow ranges for temperature and RH and permit these recommendations suggest the feasibility of Fuzzy Logically implementable control strategies.

While devising the Fuzzy Inference System for Environment Condition Monitoring and Control the factors taken into consideration are as follows-
a) Relationship between temperature and RH

1. For a fixed amount of moisture in a fixed space, the higher the temperature more the water the air can hold, so the relative humidity will be reduced as the temperature rises. For a fixed amount of moisture in a fixed space, the lower the temperature, the less moisture the air can hold; the humidity relative to its capacity to hold moisture is increased, so the relative humidity will rise.

2. Natural fiber absorbs moisture quickly and desorbs moisture slowly. Generally absorption to equilibrium occurs within hours and desorption to a lower relative humidity equilibrium takes weeks under normal conditions. In other words, natural fibers act as their own buffers to changes in relative humidity.

3. Natural fibers approaching equilibrium with relative humidity exhibit a hysteresis effect. The amount of moisture in the fiber at the equilibrium point will be different depending upon whether equilibrium is approached from a point above it or below. Typically the moisture content of the fiber at the point of equilibrium will be higher when the fiber has previously been wet (100%) and lower when the fiber has been bone dry (0%).

b) Responsiveness of textile materials to changes in temperature and RH

1. Fibers gain or lose moisture to the environment.

2. A rapid cycle of high and low humidity causes the most damage over time. The risk of damage is greater with short and extreme cycles. Slow, seasonal change within recommended ranges is acceptable.

3. Severely degraded textiles are at greater risk of damage from low RH than less degraded textiles.
4. Changes in RH can cause changes in the dimension and shape of the textile/fiber and can catalyze the chemical reactions causing the damage.

5. Higher temperatures speed up the rates of deterioration by adding energy to accelerate chemical reactions.

c) Responsiveness of associated materials to changes in temperature and RH

1. Associated materials that are part of a textile (e.g., paint, embroidery, beads, machinery parts, accessories etc) may respond at different rates to changes in temperature and RH.

2. Mounts and stabilization materials associated with textiles may respond at different rates to changes in temperature and RH. When a textile is restrained either externally or internally wide fluctuations in RH that cause significant shrinkage of the textile are likely to cause irreversible damage.

3. Hygroscopic storage materials buffer the textiles stored within them from changes in RH.

d) Role of temperature and RH on other conditions

1. At about 68º F (20º C), RH above 65% and lack of air circulation are likely to promote mold growth. However, if mold growth is already established, or if a textile has a high equilibrium moisture content, then growth can occur even at lower RH.

2. RH above 65% provides an environment hospitable to most insect pests.

3. High temperatures and/or high RH can accelerate chemical reactions. If textiles are in contact with materials that are incompatible in terms of their respective pH values undesirable reactions may occur, especially in the presence of high temperature or RH.
Monitoring Temperature and RH

This involves the following activities

- Inspection of conditions in working place and display areas at regular intervals.
- Measurement and recording of temperature and RH at test locations either continuously or at regular intervals.
- Choosing a measuring and recording device that is accurate and could be calibrated over the course of time.
- Analyzing the recorded conditions to check that the climate control and management system are working properly.

Environmental Control Methods

The methods normally employed in optimizing the Environmental Conditions are as follows-

I. HVAC (Heating, Ventilating and Air Conditioning) System
II. Heating
III. Air conditioning
IV. Humidifiers and Dehumidifiers
V. Temperate Climates Control by Electric Fans
VI. Microclimates: Climate Active or Passive Systems

Humidification System used in Textile Industry

Humidification system without chilling helps to maintain only the % Relative Humidity without much difficulty. They can be classified generally as either Unitary or Central Station. Central Station system is the most widely used system in the Textile Industry [7]. This mainly comprises two components-

1. Air moving devices comprising the Fans
2. Mixing devices for air and washer called Air Washers

Fans
In any air handling system the fan is a key component. It is a device which moves the air. This is achieved by pressurizing the air and the resultant pressure difference makes the air to move. From the fan laws the following relationship can be arrived which help in developing the control strategies for humidity control:

- Pressure is directly proportional to square of RPM
- Shaft power is directly proportional to cube of RPM

Air moving devices are always divided into two groups- one for Return Air and other for Supply Air. The return air fans return the air to the plant room from where it may circulated or exhausted in the mill, while the supply air fans supply air to the mill from the plant room. Air washer is a device for

![Fig. 3.17: Environmental parameter sensing scheme](image-url)
intimately mixing water and air. The intimate contact between these two elements is best brought about for this application by drawing air through a spray chamber in which atomized water is kept in transit.

**Air Washer**

Basic factors that determine the size of air washer are as follows-

- Velocity of air through the washer
- Type of nozzle used
- Water quantity in circulation
- Number of spray banks

Fig. 3.17 is example of system diagram of Textile Industry. This is simple and complete solution for controlling humidity and cooling the air in a textile factory. The pressurized water is atomized into very fine droplets that, when introduced into the air, are absorbed, thus humidifying and cooling the environment. *Humidity probe* can be installed up to 200 meters away from the humi-fog station, without a decline in precision. *Atomizer with fans* is atomizing nozzles and tangential fan that creates a flow of air to carry the droplets. *Humi-fog station*, this contains the electronic controller that manages the humidification system automatically, and the volumetric pump that delivers water at high pressure to create a very fine spray. The system may be having connectivity with optional supervisor i.e. computer. Which may includes the database management, serial communication and navigation software.

**Air washer systems – Textile Industry**

Clean air that is free from dirt, debris, fibers and closely maintained to desired limits of temperature and humidity is a vital necessity to the Textile Industry. Because of this need, the Textile Industry is one of the largest industrial users of air washing equipment. The use of air-washing equipment in the Textile Industry is more difficult to understand than in most other industries since there are so many different textile processes and different combinations of these processes that present in one plant. Air washers are
utilized throughout the various processes in cotton mills where raw cotton is processed into woven cotton fabric.

**Typical Textile Air Conditioning System**

In large plants, the total tonnage may be designed with a single cooling tower circuit and a single chilled water system, but in most cases, there will be several smaller systems operating independently. The tonnage and number of air conditioning systems operating in a single plant depend on the combination of textile processes being accomplished and production capacity of the plant.

Cooling towers in textile plants are fairly standard, ranging from various types of old wooden field erected towers to modern metal package units. Some systems are designed with several package towers connected parallel to all of the refrigeration machines. In other cases, each refrigeration machine condenser unit is piped separately to its own cooling tower.

Chilled water systems are piped around the average textile plant for use in air washers, process heat exchangers, and small office air conditioning units. By far, the largest user of chilled water is the air washer unit. A small textile plant may have only one refrigeration machine, one chilled water system, and one air washer unit.

When refrigeration machines are operating air washer units are supplied with 10°C chilled water from the system’s main chilled water sump. Most of the textile chilled water systems have high level float switches on the chilled water sump. This switch controls a solenoid valve on interconnecting piping between the chilled water system and the cooling tower water circuit. During summer operation, when the chilled water is dehumidifying plant air, the volume of water in the chilled water system increases. When this occurs, the level in the sump necessarily rises until it hits the limit switch. Excess chilled water then flows to the cooling tower system as makeup. This procedure conserves both water and energy since it avoids wasting excess chilled water and increases the efficiency of the condenser unit.
Typical Air Washer Unit

Just a few years ago, textile air washers were designed primarily as low-air velocity, non chilled water systems. They were so large that air-washer rooms were an integral part of the Textile building. Lint and fiber screens ahead of the washers were nonexistent in many cases, and the washer rooms were typically filled with cotton lint. The warm water in the washer was a perfect environment for bacteria. Lint, dirt, and other suspended matter in the water continually plugged air washer spray nozzles, reducing the efficiency of these units. As the Textile Industry began to install air conditioning equipment, these units were upgraded and modified so that they would perform properly with chilled water.

Air cleaning units found on textile chilled water systems today consist of two basic types: packaged air washer units and rotor spray units. Air entering either unit from the inside of the plant first passes through a fine mesh screen or drum roll filter. The function of these filters is to remove lint, dust, oil in some cases, and other debris before they get into the water in the air washer units. Some of these units have moving paper media, while others have semi permanent synthetic media that is replaced two or three times per year.

Most textile air washer systems are designed with temperature and humidity controls to automatically blend outside air with the in-plant air appropriate to the needs of the particular textile process being run in the plant. This is done through electrical or air-controlled louvers opening the intake of the washer to the outside air. The specific temperature and humidity may vary from one department to another in the same plant. This is another reason for having separate chilled water systems for different processes in a plant.

The mixture of air enters the actual washing section of the air washer unit after passing through solid cartridge type filters. Several vertical headers with spray nozzles are spaced evenly across the area of air flow. The nozzles spray water against each other so that the incoming air must pass through a wall of water two or three feet thick. This does three things to the air:
1. Washes and cleans the air
2. Saturates it with moisture
3. Controls the temperature of the air

The spray nozzle headers are connected to a recirculating pump that continually picks up water from the air washer sump and pushes it through the nozzles.

Some newer designs have automatic controls in each washer that automatically adjust the temperature of air washer sump water by letting more or less chilled water in. Automatic control valves are connected to the temperature and humidity sensing devices. This means that the amount of chilled water makeup can vary from one washer to another in a plant, but this variation is not large enough to disrupt adequate recirculation of treatment chemical being fed to the main chilled water sump.

After the air passes through the spray section of the washer unit, it passes through mist eliminator blades that function to remove condensed moisture.

There are some air washer units, particularly in synthetic plants, that do not use chilled water for the washing process. They continually reticulate the same water through the spray nozzles, except for a small amount of makeup and blow down. Permanent cartridge type metal filters both before and after the washing section are used to help keep the unit clean. These cartridge filters must be regularly steam cleaned. The eliminators sections of these washers are followed by steam reheat coils and chilled.

There are fundamental differences between summer and winter operation of textile air washer systems. A basic understanding of these differences is necessary in order to fully comprehend the water treatment problem presented.

**Summer Operation**

During summer operation, most textile air washer systems dehumidify plant air. The condensation from this dehumidification process drops into the
air washer sump and enters the chilled water system. In one day, a typical textile plant may add condensation in quantities equal to or, in some cases, greater than the volume of the entire chilled water system. This means that there will be no raw water makeup to the chilled water system. Instead, overflow from the chilled water sump goes either to the sewer or to the cooling tower through a solenoid valve.

**Winter Operation**

Winter operation of air washer systems is just the reverse. Humidification of plant air generally takes place, and the air washer evaporates water just like a cooling tower in summer. Air washer sumps are each equipped with a float-controlled makeup line so that they can be operated independently during this humidification time of the year. During this time, each washer must be bled independently to reduce the concentration of suspended solids. It should be pointed out that although the water in the air washer during winter operation becomes highly concentrated; the major problem is still fouling and not corrosion or scale formation. There is a current movement in the Textile Industry to install bypass piping around refrigeration machines so that the main chilled water pump and sump filter can be utilized all year long. The benefits of this procedure are:

- A severe fouling problem in one washer is diluted around the plant
- Chemical feed can be done from one feed point
- Sump screen filter can be used
- Standing water in idle chilled water lines is kept recirculating

Temperature and humidity are the interdependent parameters in environment. The humidity rate and temperature is an important factor for quality of yarn and finally cloth. It reduces the formation of static electricity, and needs to be adjusted according to the produced items. Equally important is the possibility of maintaining the work environment free of dusts and suspended oil particles which are more or less injurious to the health and are continuously emitted by the running machines. It is therefore essential to have
an efficient monitoring environment condition of plant, which can keep stable as much as possible the humidity rate and the temperature in the production room.

### 3.3.2 FIS for Environment Condition Determination

The inference scheme employed in Temperature and Humidity is based on the individual rule firing where contribution of each rule is evaluated and overall decision is derived. The current values of temperature and humidity are provided to the FIS of Environment Condition Monitoring which derives the output of the current environment condition with the help of the Rulebase and the database of FIS. The FIS of Environment Condition Determination is shown in Fig. 3.18. Membership functions representing the meaning of linguistic values of Temperature and Humidity. Labels of the fuzzy sets are representing the linguistic values of variables. Fig. 3.19 shows the membership functions of the input variables Temperature, Humidity and the output variable Environment condition.

![Fig. 3.18: FIS of Environment](image-url)
3.3.3 Rule Based Inference

Inference rules were developed which relate the two inputs to the output. They are summarized in the Table 3.4. As seen from the table, there are nine rules. For example, if the temperature is ‘Medium’ and humidity is also ‘Medium’ then the Environment_condition is ‘Good’.

**Table 3.4: Rule Base for Environment FIS**

<table>
<thead>
<tr>
<th>Humidity</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOW</td>
<td>Bad</td>
</tr>
<tr>
<td>MEDIUM</td>
<td>Bad</td>
</tr>
<tr>
<td>HIGH</td>
<td>Bad</td>
</tr>
</tbody>
</table>
3.3.4 Rule Viewer

The rule viewer of environment condition is shown in Fig. 3.20. The nine rules are developed for FIS of environment condition. Different conditions were generated manually in the rule view and for simultaneous evaluation have been designed and analyzed. Fig. 3.20 shows the rule 8 and rule 9 are fired and environment condition is ‘Good’ for temperature medium and humidity also ‘Medium’.

For medium temperature and high humidity the environment condition is ‘Medium’. For other cases the environment condition is ‘Bad’ which can be viewed from rule viewer of MATLAB toolbox.

![Fig. 3.20 Rule Viewer of Environment Condition](image)

3.3.5 Surface Viewer

Surface view of Environment Condition is given in Fig. 3.21 from which the operating areas of the system is identified and tuned according to get the optimal control. The Surface Viewer is used to display the dependency of
one of the outputs on any one or two of the inputs that is, it generates and plots an output surface map for the system.

A three dimensional curve seen through surface viewer that represents the mapping from Temperature and Humidity to Environment Condition. Because this curve represents a two-input one-output case, also can see the entire mapping in one plot. When we move beyond three dimensions overall, we start to encounter trouble displaying the results. When Temperature and Humidity both are ‘Medium’ then Environment Condition is ‘Good’ displaying on surface view.

3.3.6 Environment Condition Modeling

Fig 3.22 shows the Environment Condition determination Simulink model for the testing of the system performance by providing the different type of inputs. The model is designed to view the resultant output of FIS while provided with the constant Temperature and variable Humidity, so that system can thorough test. Different Simulink models are designed to simulate the Environment conditions of textile industry. The fig. 3.23 shows model with constant Humidity and variable Temperature. And the fig. 3.24 shows model with variable Temperature and Humidity.
Having number of models with slight variation in output parameter makes it handy to retune and re-simulate them to get the best appropriate model which closely matches the expected real-time results. For simulation purpose the inputs of Temperature and Humidity were provided simultaneously to the different models. To make and achieve all possible simulation conditions the both input were made of as sine wave inputs with different frequencies. The expected results were analyzed with different variation in frequencies and
amplitude of the Temperature and Humidity so that full range of output could be achieved.

![Simulink Model for Environment Condition Determination with Variable Input](image)

**Fig. 3.24: Simulink Model for Environment Condition Determination with Variable Input**

### 3.4 Lubrication Oil Tank Condition Determination

In past much has been done on the subject of lubrication from a theoretical standpoint and attempts have been made to improve the coefficient of friction in attempt to maximize the machinery life, reduce maintenance costs and extended system service life. Even today it presents an interesting field of study.

These are instances where oils have been adopted for mill work from the result of test upon friction machines. These oils when replace by other lubricants considerable power has been saved. Many difficulties arise from selecting oil for actual work by depending upon the comparative oil chemist. This is mainly because gravity, viscosity or temperature tests do not indicate the lubricating value of oil. In fact they show simply some of its physical properties. The lubricant oil differ from those oils which are not primarily
intended for the lubricating purposes in that the manufacturers of lubricant oils allow but very little variations form the standard properties.

The most practical method of making a selection of lubricant oil is by an actual trial upon the machine to be lubricated. Sometimes it is selected based upon the lasting quality. But this alone does not signify that the oil is best to use. Sometimes selections are made based on after use dry samples of lubricant. The purpose is to secure non-gumming lubricant. The best method is to place the samples on the hands of machine-operator for careful observation. However there is possibility of miss-judging the different stages of lubrication. Oil could be reported upon as “all right”, “slight difference”, “not suitable” or “it doesn’t work” etc. While selecting the oil lubricant human expertise, experience and sometime own interest play deciding role. There are many other issues and factors that go in to the selection of lubricant have been discussed in [8].

There is need to establish by which the effect of lubricants can be determined in a practical manner. Lubricant should be selected upon practical behaviour towards reducing the friction to its minimum and further it should not vary in quality, nor deteriorate during use, nor leave any traces of deposit. They should be applied conforming to nature of machine operation and the desirable results.

The textile mills are entailed with heterogeneous kind of machineries. Specific lubricant fails to serve the lubrication for entire mill. However the machineries may be grouped to decide the class of lubricant to be used. This could be as follows-

- High-pressure cylinder oil
- Low-pressure cylinder oil
- Engine oil
- Dynamo or motor oil
- General lubricant of heavy machinery
- General lubricant of light machinery
- Shafting oil
- Loom oil
- Bath or closed spindle oil
- Heavy or Light open spindle oil
- Top roll oil etc.

Every mechanism needs the lubrication in one or another form. But outside of the spinning frame no other class of machinery claims so much attention from the lubricant standpoint as looms. It is not power saving, but stainless quality is anticipated for loom oil. In attempt to secure stainless oil the power saving becomes a tricky. The proper loom lubrication is indispensable in terms of not only in power saving but also save the wear of the loom and the amount of oil used. Lubricants give different results under duplicate conditions of pressure and speed.

The stress on the yarn during the weaving process results into strains and frictions which are the more intense, the more modern and high-performing is the production machinery. To withstand the continuous wear and tear process it is therefore necessary to ensure to the fiber an optimum elasticity and a more efficient lubrication than that ensured by the batching oil. It is therefore essential to have an efficient monitoring the lubrication oil tank’s condition with the help of its quantity and pressure of oil.

### 3.4.1 FIS for Oil Tank Condition

![FIS of Oil tank unit](image)

*Fig. 3.25: FIS of Oil tank unit*
Oil_Tank_Condition FIS is shown in Fig. 3.25. This system is designed using Mamdani’s method of Fuzzy inference. Oil Quantity in the tank and Oil Pressure supplied for lubrication are the two inputs for FIS according to which the Oil Tank Condition is determined. Respective Oil pressure is required to supply the oil to the moving mechanical parts through the small venturies provided by the manufacturer of the machine. Excessive or low down oil supply pressure may cause in over-oiling, spillage or parched machine parts.

![Membership functions of Oil Tank unit](image)

Fig. 3.26: Membership functions of Oil Tank unit
with increased wear and tear. Hence the oil pressure is categorized within three overlapped ranges named High, Normal and Low pressure. The oil quantity ranges within High, Normal and Low in conjunction with Pressure range variable determine the Oil Tank Condition output. The Fig. 3.26 shows the membership functions of input variables Quantity and Pressure and output variable Oil Tank Condition. Both input MFs are of Trapezoidal type and the output variable Oil Tank Condition MF is Triangular type.

3.4.2 Rule Based Inference of Oil Tank

Rule base used is given in Table 3.5 where Mamdani’s method of inference is used. Total nine IF..Then rules are defined in conjunction with AND operator which is shown in table. These rules have been formulated by discussing with Machine expert and experienced operator.

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOW</td>
<td>Bad</td>
</tr>
<tr>
<td>MEDIUM</td>
<td>Medium</td>
</tr>
<tr>
<td>HIGH</td>
<td>Bad</td>
</tr>
</tbody>
</table>

3.4.3 Rule Viewer of Oil Tank

The rule viewer displays a roadmap of the whole fuzzy inference process. It shows the membership functions of the whole fuzzy inference process. It shows the membership functions referenced by the antecedent i.e. if-part of each rule, the membership functions referenced by the consequent i.e. then-part of each rule and represents the aggregate weighted decision for the given inference system. This decision will depend on the input values for the
The Rule Viewer allows the interpretation of the entire fuzzy inference process. The Rule Viewer also shows how the shape of membership functions influences the overall result. Rule Viewer further helps to see one calculation at a time and in great detail. In this sense, it presents a sort of micro view of the FIS that is of immense significance for optimization of final results. The Fig. 3.27 and Fig. 3.28 is the Rule viewer ‘Bad’ and ‘Good’ Condition for Oil Tank respectively.

Fig. 3.27: Rule Viewer for Bad Oil tank unit

Fig. 3.28: Rule base viewer for Good Oil tank unit
3.4.4 Surface Viewer

The entire span of the output set is based on the entire span of the input set. The surface viewer depicts the dependencies of output on the input as illustrated in Fig. 3.29. The surface viewer also shows the behavior of the system. The quantity and pressure of oil is playing important role in oil tank unit. The oil tank condition is ‘Good’ only when Oil Quantity and Pressure is ‘Medium’. Also when the Quantity is ‘High’ and Pressure is ‘Normal’ as viewed through Surface view in yellow color.

3.4.5 Lubrication Oil Tank Modeling

Modeling of Oil Tank systems begins with the determination of the relationship between input and output signals. In the case of the liquid level process as shown in Fig. 3.30, we must determine the relationship between the input flow and the output level. In the liquid level system the liquid inflow is

\[ u(t) = q_i(t) \]

Liquid Level and Tank Process System

\[ y(t) = h(t) \]

Fig. 3.30: Block Diagram of Liquid Level System
shown as \( q_i(t) \), and the outflow as \( q_o(t) \). The height is denoted by \( h(t) \) and the constant cross-sectional area of the tank by \( A \). In control systems we often refer to the process input signal as \( u(t) \) and the process output signal to be controlled as \( y(t) \). As we have only one manipulated input \( q_i(t) \), and one controlled output \( h(t) \), we classify this as a SISO system.

### 3.4.5.1 Modeling of Oil Tank Level

A tank containing liquid can be represented in terms of the height of liquid in it, the inflow volume of liquid and the outflow volume of liquid as shown in Fig. 3.31.

Where;

- Liquid inflow: \( q_i(t) \)
- Liquid outflow: \( q_o(t) \)
- Liquid level/height: \( h(t) \)
- Constant cross-sectional area of tank: \( A \)
The flow of liquid into the tank is controlled by a valve. The control input signal to the valve is a current signal (in mA) which is converted into a pressure signal. This pressure is applied to a valve that changes the valve stem position (in mm). The valve position dictates the amount of flow passing through the valve into the tank. The height of liquid in the tank is measured by a transducer (resistive gauge) which produces an output (in mA).

The physical equation governing the change in liquid volume is,

\[ \text{Rate of change of volume of liquid} = \text{inflow} - \text{outflow} \]

Thus, if the inflow was equal to the outflow then there would be no change in the volume/height or level of liquid retained by the tank.

Using above physical principle of volume/height we have,

\[ \frac{d}{dt} (h(t)A) = q_t(t) - q_0(t) \]  \hspace{2cm} (3.4)

Assume that-

1. Cross-sectional area \( A \) for the tank is constant
2. The outflow is proportional to the height of liquid, it is may be given as,

\[ q_0 = a \sqrt{2gh(t)} \]  \hspace{2cm} (3.5)

Where, \( a \) is the area of the tank outlet and inlet
\( g \) is the gravitational constant

Applying these assumptions to the differential equation for rate of change of volume/height-

\[ A \frac{d}{dt} (h(t)) = q_t(t) - q_0(t) = q_t(t) - a \frac{a \sqrt{2gh(t)}}{A} \]  \hspace{2cm} (3.6)

\[ \frac{d}{dt} (h(t)) = \frac{q_t(t)}{A} - \frac{a \sqrt{2gh(t)}}{A} \]  \hspace{2cm} (3.7)

3.4.5.2 Design of Oil Tank Model in Simulink

The level status of the oil tank according to the inflow and outflow of the oil during lubrication process is simulated by designing an oil tank model
with the flow control. Using Equation 3.7 we designed an oil tank level model with the help of blocks in Simulink library of MATLAB as shown in Fig. 3.32. In this model we can adjust the lubrication flow rate according to the machine and get the current oil level state for our Lubrication oil tank condition monitoring FIS. It gives the level of oil in the tank for the corresponding inflow and outflows. Fig. 3.32 shows a Simulink model designed in MATLAB environment to study the response of oil tank level model for the change in inflow and change in load.

**3.4.6 Oil Tank Condition Modeling**

Fig. 3.33, Fig. 3.34, Fig. 3.35 shows the Lubricant Oil Tank Condition determination Simulink model for the testing of the system performance by providing the different type of inputs reflecting the different liquid tank conditions. The model is designed in Fig. 3.34 to view the resultant output of FIS while provided with the constant Quantity and variable pressure, so that
Fig. 3.33: Simulink Model for Oil tank unit with pressure constant

Fig. 3.34: Simulink Model for Oil tank unit with quantity constant

Fig. 3.35: Simulink Model for Oil tank unit with variable input

The system can thoroughly tested and validated. Having number of models with slight variation in output parameter makes it handy to retune and re-simulate them to get the best appropriate model which closely matches the expected real-time results.

To make and achieve all possible simulation conditions the both input were made of as sine wave inputs with different frequencies. The expected
results were analyzed with different variation in frequencies and amplitude of the Quantity and Pressure so that full range of output could be achieved.

3.5 Machine health:

The Machine Health Status is shown on Fig. 3.36. The Textile machine affects due to the following main sections like Environment Status, Motor Status, Oil Tank Status and Emergency Faults. All these units determine the Machine Health and in any case conditions close to Good Machine Health are anticipated in view of improving efficiency and cloth quality. The machine health like Bad, Medium and Good are fuzzy in nature. It will signify the important hints towards the machine maintenance.

![Figure 3.36: Machine Health status](image1)

3.5.1 FIS for Machine Health Determination

![Figure 3.37: FIS Machine Health determination](image2)
FIS for Machine Health determination is shown in Fig. 3.17. Environment, Motor Condition, Oil Tank and the Emergency Faults are the four inputs for Machine Health FIS that determines the Machine Health. It may be Good, Bad or Medium which directly depends on the input parameters.

3.5.2 Modeling of Machine Health Determination

The modeling of machine health determination is designed in MATLAB toolbox. The machine health is depends upon the different parameters. The Environment Status, Motor Condition, Oil Tank unit and Emergency faults are the inputs which are displayed on scope for further analysis. In this modeling the Environment Status, Motor Condition, Oil Tank unit are the sine inputs of different amplitude and different frequency encompassing the entire range of input conditions.

![FLC for Machine Health determination](image)

Figure 3.38: FLC for Machine Health determination

3.6 References:

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7. Misza Kalechman, Practical MATLAB Applications for Engineers - CRC Press.


