## Table of contents

1. Contents 2
2. Abstract 4
3. Dedication 5
4. Introduction 6

5. SECTION 1: Preparation of glass/epoxy laminates (4 plies) with porosity < 7% 7

6. SECTION 2: Production of film by BESCHCHITUNG 16
   a. Principle of Machine 17
   b. Working/Operation of Machine 17
      i. Determination of temperature and time parameters for production 17
         1. Temperature of production 17
         2. Time (safe time) of production 18
         3. Curing of resin (unstirred condition) 18
      ii. Machine operation (production of film) 18
         1. Paper roll selection (orientation and direction of rotation) 19
         2. Paper roll installation 19
         3. Resin heating & pouring 19
         4. Production of film 20
            a. Start of machine 20
               i. Capacities of Machine 20
               ii. Integrity & Consistency Check 20
               iii. Modes of Operation 20
                  1. Auto Mode 20
                  2. Hand Mode/Manual Mode 22
                  3. Experimental Operation 23
            b. Control of machine 24
      b. Testing of film 25
         a. Tack 25
            i. Peel Off test 25
               i. Variant A (Double Layer Method) 25
               ii. Variant B (Single Layer Method) 26
            b. Sticky finger test 26
         b. Thickness 26
         c. Spread 26
         d. Durability 26

6. Problems/Trouble Shooting 26
   a. Entrance of air in the system 26
   b. Paper Roll alignment/Change of position/sequence of passage of paper 27
   c. Vertical adjustment of roll assembly 29
   d. Design Changes 29
   e. Reasons for Delay in Operation of Bechichtung 30
   f. Tabulation of Results 30
7. SECTION 3: Drum winding of carbon fiber for production of prepreg laminates
   a. Principle 34
   b. Working 34
   c. Consistency check 36
   d. Modes of Operation
      i. Auto Mode
         1. Selection of input width 37
            a. Method 1 37
            b. Method 2 38
            c. Method 3 38
            d. Conclusions 40
            e. Cautions 40
      ii. Manual/Hand Mode 41
   e. Problems encountered during operation 41
      i. Spacing of fiber 41
      ii. Bobbin misalignment from center 42
      iii. Speed calculation/Ratio of diameters 42
      iv. Tension adjustment/countering 42
      v. Empirical Formula 1 (input width + factor) 44
      vi. Empirical Formula 2 (input width + factor) 44
      vii. Changing the direction of orientation of fiber on rolls 44
      viii. Changing the position of rolls 46
         1. in horizontal direction 46
         2. in vertical direction 46
      ix. Roll Control assembly 46
      x. Brake speed adjustment 47
      xi. Balancing load 47
      xii. General inference 1: 47
         xiii. Adjustment by incorporating vertical tension relieving assembly 47
   f. Production of laminates at temperature of 47
      i. 60 C 47
      ii. 65 C 47
      iii. 70 C 47
   g. Reason for Resin de-adhesion on drum winder 48
   h. Checkout of fiber volume fraction of composites 48

8. Conclusions 50
Abstract

Manufacturing of composites consists of step by step processing via various processes to reach final finishing product. Present work is focused on manufacturing of same by Vacuum Assisted Resin Infusion (VARI), BESCHICHTUNG and DRUM WINDING Processes. These techniques are applied to produce Prepreg used for Aerospace applications. Focus has been placed on establishing a procedure to carry out the process, optimization of process parameters to achieve maximum production efficiency. End results of whole exercise have been found to have good agreement with established criterion.
Dedication

This work is dedicated to Herr Ferencz, Herr Sumser, Herr Filipe Wolff-Fabris, Herr Wolfgang Lupp & Frau Sonja Rhodes for their supportive & facilitating attitude all through out my stay.
4. Introduction

Present work is focused on development of composite prepregs using combination of Vacuum assisted resin infusion (VARI), BESCHCHTUNG, Drum Winding and autoclave processes. Focus has been placed on using the above mentioned technologies with their full potential to reach at an optimized laminate and workable composite structure. The work has been divided into various tasks, each describing techniques of individual process in detail.
5. SECTION 1:

Preparation of glass/epoxy laminates by vacuum assisted resin infusion process (VARI)  
(Objective: Laminates with porosity below 7%)

**Equipment:** Aluminum base plate, putty plate, nozzle, stoppers

**Material:** Epoxy resin (70% vol.), hardener (30%, vol.), glass fibers, putty tape, vacuum bagging (Vakuumbagging), flow assisting cloth (Fließhilfe), cover cloth (Abreißgewebe), spiral pipe (Vakuumspiralschlauch), normal pipe, connectors

**Procedure:**

**Preparation of VARI Assembly**

1. Prepare the base aluminum plate. Clean it thoroughly initially with scraper to remove all the previously attached unwanted cured resin. Wash it with acetone to get fresh, clean and dry surface.
2. Leave the clean surface for drying for about an hour to get it dry and get dried surface.
3. Make the putty tape boundary all along the edges of the plate
4. Inside the boundary put a thin layer of free coat, avoiding the putty tape boundary.
5. Cut the glass fiber mat, 55 x 55 mm and put it in the middle of putty tape boundary, leaving approximately 25 mm from all sides.
6. Prepare pipe connections
   a. Entrance side connection:
      i. Leave approximately 25 mm gap between GF ply & putty tape boundary.
      ii. Wound putty tape on pipe approximately 12 mm away from cut end & circulate the cover cloth (Abreißgewebe) all around the putty tape so that it sticks to the putty tape.
      iii. Place the cloth covered pipe on the entrance side in such a way that all the cloth covered region falls inside the putty tape boundary.& other end is away from glass fiber ply about 2-3 mm.
      iv. The region of pipe outside the putty tape boundary is securely fastened by clamp-type putty tape joints so that pipe motion could
be reduced as much as possible. To further enhance the strength of joints two pieces of putty tape are placed onto the pads of earlier made joints.

b. Exit side connections
   i. In the same fashion as done for entrance side connection, prepare the exit side connection by circulating putty tape on the pipe & attaching cover cloth onto the putty tape and then placing the pipe & cloth inside the main boundary of putty tape. (As shown in Fig 1). The region of pipe outside the main putty tape boundary is encircled and tightened by two joints of putty tape in such a way that pipe is securely fastened and there is no room for it to move. To further enhance the strength of joint two pieces of putty tape are placed onto the pads of earlier made joints similar to the way as was done for entrance side joints.

![Figure 1: Exit side connections of VARI assembly](image)

7. After making the joints, put the cover cloth (Abreißgewebe) cut approximately 15 mm greater then the dimensions of GF on top of glass fiber ply.
8. After this place the Fließhilfe cut exactly to the dimensions of GF on top of Abreißgewebe.
9. Finally, put Vakuumbagging on top of all and attach it to the putty tape so that sealing action could be accomplished. Vakuumbagging is pushed tightly onto the putty tape and onto the pipe connections to form VARI assembly.
10. The assembly is then tested for leakage by putting clamps on entrance side and applying vacuum on exit side. The vacuum level is set at 3 mbar and tested for minimum reached vacuum. The value if reached is 10 – 18 mbar. This is considered to be good. (As shown in Figure 2 & 3 below)

**CAUTIONS**
a) Make sure that the Abreißgewebe should not touch the putty tape boundary in any case and should be away from it by at least 10 mm from all sides. This will help in adhesion of putty tape to metal surface. Otherwise, the presence of Abreißgewebe near the putty tape, increases the chances of deadhesion of bond between tape and metal as Abreißgewebe help resin (liquid) to penetrate in the interface of metal and putty tape and decreases the binding power.

b) The entrance and exit side pipes should be provided to be long enough to have minimum stresses on the putty tape joints. Specially, entrance side pipe should be long to allow for it to be dipped in the resin mixture.

c) The clamp should be placed on the pipe as far as possible from putty tape joint on the entrance side & on the exit side. This allows sufficient space for the resin to be sucked from the bath and room for trapped air to be sucked on the exit side.

d) If possible, as an option, a resin trap could be placed on the exit side pipe, this trap allows extra resin to go to flask before going to vacuum pump in case of excessive suction of resin.

Figure 2: Complete/final VARI Assembly
**Figure 3**: Vacuum level indication on Vacuum pump for VARI setup testing.

**Preparation of resin**

Resin is prepared in following steps

1. Resin is taken from resin container (70% wt.)
2. 30% of Resin is taken as hardener.
3. Both are mixed in a large container and then stirred by automatic stirrer to completely homogenize the system.
4. The mixture is then placed in vacuum chamber to degass. The capacity of vacuum is taken up as 20 mbar (house vacuum). At this vacuum the resin is given enough time (30 minutes) to completely degass it. (It degass in three states, slight bubble formation, enlargement of bubbles and then finally dissolution of bubbles to get bubble free completely degass state)

**Injection of resin**

Final step consists of injection of degassed resin in the VARI assembly. The procedure is described below in steps

1. The entrance side pipe is dipped in the resin mixture container
2. The system which is at 14 mbar pressure is made to take the resin by opening the clamp on the entrance side pipe slowly.
3. The resin goes into the system slowly. The initial front of liquid consist of mixture of bubbles of air and resin which progress slowly to form later fronts as described below.

Three distinct fronts/zones are formed in VARI injection process

a. **Bubble region**: In this region/zone bubbles are formed as a result of interaction of air already present in system with first injected liquid layer. This liquid/air front travels slowly under Fließhilfe, getting its help, wetting the fibers. Bubbles of air also come from the small amount of air present in the resin after degassing. These tend to move in front as under vacuum they have the tendency to escape from system in advance to liquid resin. The bubble region progresses slowly creating another region behind it as described below.

b. **Semi dry region**: This is region preceding the bubble region. The bubbles of air are no more present while fibers are partially wetted. Almost 80% of fibers are wetted in this region. This advances slowly creating completely wetted region. The distinct recognition of this region is the light blue color as contrast to blue color of Fließhilfe.

c. **Completely wet/liquid region**: After semi dry region there comes a completely wet region/liquid region. The liquid completely penetrates into the inter layer regions of fibers and Fließhilfe wetting both and forming
blue color of Fließhilfe. No fibers are left dry and all are completely impregnated and wetted.

4. After, the resin is completely fed into the system, a little time (approx. 1-2 minutes) is allowed for it to be sucked into exit side pipe. This helps for the entrapped gases to be sucked out of the system and provide gas free system.

5. After the system is full of air or gas free resin, exit side clamp is closed first and then entrance side clamp is closed.

**CAUTION:** Take care while following the sequence of closing the clamps. ALWAYS first close the exit side clamp and then entrance side clamp because if the order will be reversed then all the resin in the system will be sucked by the vacuum pump before the clamp (exit side) could be closed. If the exit side clamp is closed first then resin will stay in the system and will not go out as there is no pressure on the system & it will not go out from entrance side as there is no reverse pressure on it as well.

6. After the clamps are closed, the pipe connections are cut from entrance and exit side and prepared plate is taken to next step of curing.

**CURING**

Curing is the final step in the manufacturing of composites by VARI. In this step resin filled system is placed in heated Oven. The part is cured at 80°C for typically 8 hrs. This step makes the hardener to react with resin and form the final composite.

**CAUTION:** VARI prepared plate is placed in Oven carefully avoiding excessive stresses on the entrance & exit side connections. The connections are very week & critical point to be taken into consideration as any excessive pressure on these would cause putty tape to de adhere from its place (from metal) at high temperature and cause air to get in, which could ruin the whole part.

**POST CURING OPENING**

After 8 hrs are passed, the part is taken out of Oven and taken on scrap table. It is visually inspected for any defects and then opened with the help of scraping tools. Care is taken not to destroy/damage the surface of composite being manufactured as it will badly affect the properties.

**SAMPLING**

After the part is scraped & opened, it is marked for sampling in following sequence

<table>
<thead>
<tr>
<th>Size (mm)</th>
<th>Qty (No)</th>
</tr>
</thead>
<tbody>
<tr>
<td>55 mm x 55 mm</td>
<td>3</td>
</tr>
</tbody>
</table>

Their complete dimensions are noted as shown in Figure 4 below
V = \frac{55.089 \times 55.1132 \times 2.56}{3} = 7.77 \text{ cm}^3

V = \frac{55.05 \times 55.14 \times 2.60}{3} = 7.89 \text{ cm}^3

V = \frac{55.075 \times 55.12 \times 2.57}{3} = 7.80 \text{ cm}^3
Figure 4: Sample for determination of porosity
These samples are cut into above shown dimensions with the help of rotary blade cutter. After this, the samples are placed in the aluminum dishes for burning them in the furnace so that the resin content of the composite could be burned and fiber content could be obtained for measurement of fiber volume percentage.

BURNOUT PHASE

In the final burnout phase the samples are placed in the furnace in Petri dishes. Samples are placed for 2 hrs at 625°C until the resin phase of composite is burned out.

CAUTION: A proper furnace should be selected while burning the samples. An electric resistance or inductance furnace is the best suit. However, in case of gas fired furnaces, the samples should be placed in such a way that the circulation of hot air in the furnace may not cause the fibers to go/swirl in the air.

a) One way of doing that is to place the samples in ceramic Petri dish and cover them with a piece of metal such as iron plate and then place it in the furnace. This cover of some heavy metal piece will help block the passage of air to the sample.

b) Second way of doing that is to place the mouth of Petri dish in a direction opposite to the hot air blower in the furnace. This somehow, helps to stop the effect of fast air on the samples and stop them from going out from Petri dish when they are free from resin matrix.

c) A third way is to place the composite pieces in a long glass beaker with deep pan. This will also reduce the effect of fast circulated air onto the fibers.

After burnout, the samples are taken from furnace and placed on weighing balance. Then the porosity is calculated as per procedure below.

Porosity Calculations:

\[ \rho_R = \frac{\text{Weight of composite}}{\text{Volume of composite}} \]
\[ \rho_T = \frac{\text{Weight of fiber}}{\text{Density of glass fiber}} \]
\[ X_f = \frac{\text{Volume content of fibre}}{\text{Volume content of composite}} \]
\[ X_m = 1 - X_f \]
\[ \rho_T = X_f \rho_f + X_m \rho_M \]
\[ \rho_R = \rho_T \left(1 - \text{porosity}\right) \]
\[ \text{Porosity} = 1 - \frac{\rho_R}{\rho_T} \]

CASE 1

Weight of composite = 13.94 g
Volume of composite = 7.77 cm³
Weight of fibre = 9.66 ± 5 g

\[ \rho_R = \frac{\text{weight of composite}}{\text{volume of composite}} \]
\[
\rho_R = 13.94 / 7.77 \\
\rho_R = 1.794 \text{ g/cm}^3 \\
\text{Now, density} = \text{mass/volume or} \\
V = m/d \\
\text{Volume content of fibre} = \text{weight of fibres} / \text{density of fibres} = 9.66/2.6 \\
\text{Volume content of Fibre} = 3.71 \text{ cm}^3 \\
\]

\[X_f = \text{Volume content of fibre} / \text{Volume content of composite} \]
\[X_f = 3.71/7.77 = 0.477 \]
\[X_m = 1 – X_f \]
\[X_m = 0.522 \]

\[\text{Density of (} \rho_T \text{)} = X_f \rho_f + X_m (\rho_m) \]
\[\rho_T = (0.477) (2.6) + (0.522) (1.2) \rho_T \]
\[= 1.2482 + 0.6264 = 1.8746 \]
\[\rho_R = \rho_T (1 – \text{porosity}) \]
\[\text{Porosity} = 1 – \rho_R / \rho_T \]
\[\text{Porosity} = 1 – 1.794 / 1.8746 \text{ Porosity} = 4\% \]

**CASE – II**

\[\text{Weight of composite} = 14.01 \text{ g} \]
\[\text{Volume of composite} = 7.89 \text{ cm}^3 \]
\[\text{Weight of fiber} = 9.84 \pm 5 \text{ g} \]
\[\rho_R = \text{weight of composite} / \text{volume of composite} \]
\[\rho_R = 14.01 / 7.89 \]
\[\rho_R = 1.7756 \text{ g/cm}^3 \]
\[\text{Now, density} = \text{mass/volume or} \\
V = m/d \\
\text{Volume content of fibre} = \text{weight of fibres} / \text{density of fibres} \]
\[= 9.84/2.6 \]
\[\text{Volume content of fibre} = 3.78 \text{ cm}^3 \]

\[X_f = \text{Volume content of fibre} / \text{Volume content of composite} \]
\[X_f = 3.78/7.89 = 0.479 \]
\[X_m = 1 – X_f \]
\[X_m = 0.5209 \]

\[\text{Density of (} \rho_T \text{)} = X_f \rho_f + X_m (\rho_m) \]
\[\rho_T = (0.479) (2.6) + (0.5209) (1.2) \rho_T \]
\[= 1.2454 + 0.62508 = 1.87048 \]
\[\rho_R = \rho_T (1 – \text{porosity}) \]
\[\text{Porosity} = 1 – \rho_R / \rho_T \]
\[\text{Porosity} = 1 – 1.7756 / 1.87048 \text{ Porosity} = 5.02\% \]
CASE – III

Weight of composite  = 14.11 g
Volume of composite  = 7.80 cm³
Weight of fibre = 9.90 ± 4 g

$\rho_R = \frac{\text{weight of composite}}{\text{volume of composite}}$

$\rho_R = \frac{14.11}{7.80}$

$\rho_R = 1.8089 \text{ g/cm}^3$

Now, density = mass/volume or

$V = \frac{m}{d}$

Volume content of fibre = weight of fibres / density of fibres

$= \frac{9.90}{2.6}$

Volume content of fibre = 3.80 cm³

$X_f = \frac{\text{Volume content of fibre}}{\text{Volume content of composite}}$

$X_f = \frac{3.80}{7.80} = 0.4871$

$X_m = 1 - X_f$

$X_m = 0.5128$

$\rho_T = X_f \rho_f + X_m (\rho_m)$

$\rho_T = (0.4871)(2.6) + (0.5128)$

$1.266 + 0.61536 = 1.88136$

$\rho_R = \rho_T (1 - \text{porosity})$

Porosity = 1 – $\frac{\rho_R}{\rho_T}$

Porosity = 1 – 1.8089/

1.88136 Porosity = 3.85%

Results & discussion:

The results show that the porosity level is well below desired/targeted 7%.

The reason for this is that, fiber volume percentage present in the composite is low enough to allow the liquid to flow, which causes full impregnation of fibers in composite, wetting all regions of fibers in matrix and results in such low porosity. This low porosity is also caused by homogeneous filling of matrix avoiding formation of bubbles which promotes decrease in viscosity.

A further increase in fiber volume percentage will cause hindrance to the flow of liquid in matrix and restricts impregnation as well which eventually results in increased porosity level. Also, more fiber volume percentage will cause fibers to suck to the pump thus generating another reason of increase in porosity and disturbance in morphology of composite as well.
6. SECTION 2: Production of film by BESCHICHTUNG
This is a process of production of thin resin films on glazed (coated) paper by allowing resin to be deposited on paper while passing it through a control set of dies.

The machine used for this purpose is INATEC GmbH’s BESCHICHTUNG and the process is described as follows

a. **Principle**: Principle of operation of BECHICHTUNG is the temperature dependent flow of resin/fluid through system of pipes and dies and its deposition on paper moving underneath based upon adhesive behavior of fluid & paper under the action of shear forces resulted from the motion of fiber. Hydrophobic and hydrophilic nature of paper towards liquid also plays an important role in the formation, spread, stability & duration of film.

The higher the temperature, higher will be the fluidity of the resin (less viscosity) and easier it will be for it to flow through the systems of pipes and dies to deposits on to paper provided the turbulence in system is avoided. The same temperature change behavior also affects the other properties of liquid such as curing of resins etc. In any case the operating temperature of machine is to be kept below curing temperature of resin in order to avoid the curing of later inside dies.

b. **Working/Operation of Machine**

Machine is semi-automatic programmable logic controlled (PLC) unit. Main parts of machine are die system, control system (PLC), electrical power and control unit, main frame and roll assembly. Working of machine can be categorized into two main steps.

1. Determination of temperature & time parameters of production
   a. Temperature of production
   b. Time for production (safe time)
   c. Curing of Resin (Unstirred condition)
2. Machine operation (Production of film)

i. **Determination of temperature & time parameters for production**

Before subjecting resin for production of film in machine, following steps/procedures are adopted to get optimized values of temperature and time for production.

a. **Temperature of production**

1- Test the neat resin 438 for viscosity at the BESCHICHTUNG to get an optimum temperature at which nice film could be obtained (62°C in present case)
2- Put the same neat resin in viscosity machine, test change in viscosity at different temperatures and obtain viscosity temperature plot.
3- On viscosity – temperature plot, note the viscosity value against that temperature (e.g. 10 Pa-s)
4- Take this viscosity value & from viscosity – temperature plot of 438: DDS get temperature (working temperature) for same (72°C). (safe side (80°C)) (safe side upper temperature is taken as it will help get higher fluidity avoiding clogging of tubes/settling of resin in machine during operation)
5- Check resin (438+DDS) mixed & stirred) for its behavior to get solidified at 80°C (i.e how much time it requires to attain completely cured state. At 80°C (safe side temperature) this will be helpful to decide about cycle time of resin in machine.

b. Time (safe time) of production

For determining safe time for production following simple test is carried out to check curing of resin over time.

c. Curing of resin (unstirred condition): 438 + DDS formulation in unstirred condition have following behavior

<table>
<thead>
<tr>
<th>Day</th>
<th>Time</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>20/8/2009</td>
<td>10:30 AM</td>
<td>Semi-solid uncured</td>
</tr>
<tr>
<td>20/8/2009</td>
<td>11:45 AM</td>
<td>Semi-solid uncured</td>
</tr>
<tr>
<td>20/8/2009</td>
<td>01:00 AM</td>
<td>Semi-solid uncured</td>
</tr>
<tr>
<td>20/8/2009</td>
<td>02:00 AM</td>
<td>Semi-solid uncured</td>
</tr>
<tr>
<td>20/8/2009</td>
<td>03:30 AM</td>
<td>Semi-solid uncured</td>
</tr>
<tr>
<td>21/8/2009</td>
<td>09:00 AM</td>
<td>Semi-solid uncured</td>
</tr>
<tr>
<td>21/8/2009</td>
<td>02:00 PM</td>
<td>85 – 90 % Cured</td>
</tr>
<tr>
<td>21/8/2009</td>
<td>10:00 AM</td>
<td>100 % Cured</td>
</tr>
</tbody>
</table>

Time taken by resin to cure is noted and taken as reference time which **must not** exceed during final production process when the resin is in the machine. Otherwise, the resin will settle in the machine. That’s why temperature is kept little on high side and time is noted strictly to be kept under control to avoid any trouble. Further in addition to ensure the safety and long life of machine, at the end of every cycle machine should be purged with clean resin to clean the die system and tubes. If not purged, resin will settle in the machine and severely affect the performance of machine for future runs.

**Purging**: Procedure of purging is to put the liquid (clean resin) in machine & leave it in closed circuit condition for 2 hours and then open and drain.

**NOTE**: In stirred condition, resin settles even more quickly than in unstirred condition.

ii. Machine Operation (Production of film)

After establishing initial processing parameters, needed for production of film, machine is started. Machine startup consists of following main steps.
a. **Paper roll selection**

Paper for production of film is selected based upon its surface characteristics i.e. how much ability it carries to adhere to the surface of liquid (hydrophilic and hydrophobic characteristics).

There are two types of silicon paper which may be used on machine.

1. 23070 – Leicht trennend (exit side reverse wound) (remedies)
   - Change in the design of machine by uplifting or having arrangement for uplifting
   - Instruct supplier: to wound it clockwise to ensure its passage below exit side tension roll (this should be included in P.O issued to supplier under heading) of special requirements.
   - Allow the passage of entrance side roll directly to winder from process rolls & exit side roll paper (23070) to pass below exit side tension roll. This could facilitate the making of film.

2. 23193 – Schwer trennend: This is used on entrance side roll

3. **Paper roll installation**

Paper roll is installed in following way:

a. The air jacks are loosened at the entrance side and exit side feed and winding roll respectively. This is done to create a space for injection of paper roll onto coilers (winder and winding).

b. In second step one side of each of entry and exit side roll is taken up from a saddle by uplifting it. The saddle is designed in such a way that it could be easily skid from its position by slipping it.

c. After inserting roll onto axles, rolls are tightened by uplifting air jacks by pressurizing them with air pressure.

d. Measure, level and airtight the insert/primary roll

e. During the process of insertion and tightening, centering of roll is also taken care of in order to ensure that rolls should not be centre less as this would create problems later on.

4. **Resin heating & pouring**

Resin is heated externally in an oven to its melting state in following steps:

a. A certain quantity of resin is measured to be used for operation. (2 Kg) (2 Kg is taken to counter for any losses in and out of machine and also to maintain a certain head required for keeping hydrostatic pressure on the system.

b. The same is put in the oven to melt it to its liquefaction state. A little more time is given to it to achieve super liquid state (a state where resin’s viscosity becomes more low)

c. The same is put in the cavity of machine and allowed to settle over wire gauze.
d. The machine is started which starts sucking the resin inside the piping system.

5. Production of film

i. Start of machine

1. Capacities of machine

Maximum and minimum capacities of the machine are as follows:
- Maximum production capacity of unit = 5 m/min
- Maximum achievable rpm on pump (auftragskopf) = 60 rpm
- Minimum achievable rpm on pump (auftragskopf) = 1 rpm
- Maximum paper on rolls = 60 m

2. Integrity & consistency check

First of the machine is checked for consistency and integrity. Machine integrity is checked in following steps:

a. Visual inspection: All parts of the machine are checked for their integrity, consistency & dimensional accuracy by inspecting them with naked eye.

b. Air pressure check: Air pressure coming to and going out from the machine is checked. Air pressure valves are opened first to develop optimum air pressure for opening of pneumatic valves on the dies which otherwise will not function & also for function of Auftragskopf which will not work without air pressure as well.

c. Electrical check: Electrical connections and their mains are checked.

3. Mode of Operation

BECHICHTUNG may be operated in two modes:

a. Auto Mode
b. Hand Mode

These are selected on the basis of requirement of film (resin deposition) on paper and type and characteristics of resin.

a. Auto Mode:

Auto mode is selected when there is no fear of resin curing with temperature i-e resin is tested to remain as liquid for long enough time at room temperature without curing. The steps to be followed for the operation of Auto Mode are:

1. Push the start button on the LCD of the machine then
2. Motoren then
3. Auftragskopf (starting motor) winder and then
4. System
Figure 5: Start of machine

Figure 6: Motoren: Acknowledgement of Gerät (startup) (EIN) and with that Auftragskopf (startup) (EIN)

Figure 7: System: Module Auftragskopf (Klebstoff (EIN) und Betriebsart (Kleben from Spulen))
Machine is set to Automatic from **Start Window** & then from System – mode, Betriebsart is set to Kleben from Spülen, while Klebstoff is set to EIN from AUS and Module will automatically changed.

This ensures the opening of plunger pneumatic valves for the delivery of resin upon pressing by Aufwickler (i.e. drive roller/winder) during the operation of machine. (shown in Figure 4).

**Figure 8**: Aufwickler (motor operated screw driver used to push resin onto paper from dies)
This Klebstoff can also be operated during the operation of machine from Motoren und Auftragskopf window. Upon doing that machine calculates the rotational speed of auftragskopf und aufwickler automatically and then based upon that information calculates the amount of resin coming out from die nozzles.

b. **Hand Mode**

This is usually used when cleaning of system of machine is desired. Procedure to operate machine in Hand Mode remains same apart from that in hand mode, from system window, mode is selected and from mode (Auftragskopf) window Spulen is set to EIN from AUS.
This allows the pneumatic valves to be opened at will and allows more resin to be deposited onto paper per square meter. (which in turn depends upon speed of auftragskopf)

c. **Experimental Operation:**

<table>
<thead>
<tr>
<th>Time</th>
<th>Condition in tank</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 sec</td>
<td>transparent</td>
</tr>
<tr>
<td>10 sec</td>
<td>a little milky</td>
</tr>
<tr>
<td>15 sec</td>
<td>milky and opaque</td>
</tr>
</tbody>
</table>

Do the melting test to check the curability of resin (30 min at 80°C), if it shows no softening then it is cured. One reason could be that reaction between 438 epoxy & DDS did not completely take place (an evident of this is that DDS remained as particles in 438 epoxy even after mixing). Another solution is to heat the material @ 120°C for several hours (21 – 22 hrs) to check its curing behavior.

Resin (Epoxy 75%) + Hardener (25%) (Amine)
150 g  50 g
Heat the resin (90g) only at 120°C to decrease viscosity & increase the tendency to react. Add the hardener DGEBA + 4, 4 DDS. Resins are not good for BESCHICHTUNG as @ RT they have too low a viscosity to process further in the production process. So, new formulation is resin 438 + 4, 4 DDS.

Hardener, in case of bubbles in resin while opening resin injection valve, following may be adopted as remedies for problem:

a. Clean the filter after every 4 weeks.
b. Give good fluid head to counter any air entrance in system.
c. Clean the mechanical nozzle portion of die of machine by pulling out the main screw rod which connects/operates the die/nozzle. Re-fix it afterwards to get the smoother operation.
d. Operate the machine in Auto mode.
e. Safety valve pressure determines the closing/opening of safety valve both at die and in the tank to allow the resin to go back from die to tank in case pressure exceeds that valve.

Another solution is to heat the materials @ 120°C for several hrs to check its curing behavior (21 – 22 hrs).

Presently, a certain roll speed is to be selected & film deposition is checked to be uniform at a certain temperature at which we already know the viscosity. If film deposited is uniform then this is optimum viscosity at that temperature, otherwise change roll speed to get uniform film 1 < 5 > m/min repeat the same procedure.

ii. Control of machine

Following steps should be monitored for the operation of machine:

2. First power is turned ON by switching ON the main power from power supply. This release the power to the machine from main power unit.
3. TURN ON the main control unit from a button underneath the unit. (Red)
4. The unit is switched ON from the LCD of the machine and its mains are given time for relaxation, homogenization and normalization. Upon which the main unit releases and get a little time for coming to normal state.
5. Gerät is switched ON, which releases main power to machine. Gerät is a main power unit which consists of Inverter which control & regulates the flow of current to the machine’s other parts.
6. Five minutes are given to Great after opening so that it can get optimum speed and rotation. After 5 minutes, main air valve coming to the machine is opened automatically and observed that it releases air to machine.
7. Tank and dies temperatures are setup. Keep the temperature of pipe 10°C higher then die temperature in order to ensure smooth flow of resin from pipe to die and allowed time to get to their set states. As soon as temperatures are normalized,
machines becomes ready for operation and all signals from and to the machine indicate the further operation of machine. Auftragskopf and Great indications on the machine become clear and it became ready to operate to next step.

8. Auftragskopf is switched ON this allows power to go to machines rotation unit. After this machine is allowed some time to go to normalization.

9. Auftragskopf speed is adjusted as per requirement of the film

10. Aufwickler (primary roller) (driver) is started from LCD, which drives the paper onto it and also force driven roller (secondary roller) to release the paper. This Aufwickler is controlled manually in case of MANUAL MODE of operation. The maximum speed of aufwickler is 80 rpm which is adjusted automatically in case of AUTO MODE as per requirement of film thickness being deposited on paper.

11. As the machine starts, the resin starts coming out from dies and start depositing on paper. As paper progresses, former creates a continuous homogenous layer on the paper based upon hydrophilic and/or hydrophobic character of paper and cohesive &/or adhesive nature of resin towards paper.

NOTE: For testing purpose = 5m @ 50, 75 & 100 @ 0,5 m / min

6. Testing of film

Following tests are to be carried out on the film being produced from machine.

a. Tack

Tack of film could be tested by any of following (in house proposed) methods

   a. Peel-off test

      i. Variant A (Double layer method)

In this test one laminate of film (carrying resin film (named as A) is placed on top of other one (named as B) and given some time for developing adhesion. This bond is then broken by pulling apart the two lips of the laminates away from each other (Mode 1 fracture), while force required to do that is measured and taken as a measure of energy required to cause this fracture.

![Figure 10: Peel off test, Mode 1 fracture](image)
ii. Variant B (Single layer method)

In this method a layer of laminate is folded and made to stick onto itself, given time and then both layers of laminates are pulled apart from each other by shear force applied across the lips of laminates.

b. Sticky finger test

In this test simply finger is placed on the surface of deposited film and tack is checked by means of de adhering of finger from film surface. The stronger the tack, stronger and longer the finger will be adhered to film surface. The pull of finger from film is measured by lightly pulling the former from later and its ability is taken as measure of tack.

b. Thickness

Thickness of film is measured by means of

c. Comparison method: Height of paper is measured dry (w/o film) and then with film and both are compared.

d. Film Gauge: by means of noting the thickness of film developed on the surface of paper which could be measured by means of a thickness measuring device. The thickness has range in microns.

c. Spread

Spread is a measure of homogeneous distribution of resin on the surface of paper without causing voids/free spaces. This spread could be measured by

d. Naked eye observation: Visual observation is used to check how much resin has been spread on the surface of film. Only a tentative, generalization is drawn.

e. A leveler which could give measure of homogeneity of film on paper surface

d. Durability

Durability of film is the measure of its ability to stick to the paper for a long enough period of time without going through separation or void formation i-e creating gaps on its surface due to its deadhering from surface due to poor adhesive forces and strong cohesive forces among the particles of resin film being produced.

7. Problems/trouble shooting

a. Entrance of air in the system
During the operation of machine resin injection valve stopped working as a result of which resin stopped going into the machine and air started appearing in the resin tank from injection side nozzle. Air comes in the system exactly when pneumatic valves are opened (special consideration). This air in the system should go out from time to time via a valve (safety valve). This valve is closed, due to one of following reasons.

Sensor stops working due to

a. carbon deposition on it
b. electric discharge
c. Dissociation of BOX to generate free carbon which deposits onto sensor to block its effect.

In finding solution an obvious question was, where the Air come from? Air could come in the system by any of following reason.

d. Seal is damaged
e. Safety Valve is blocked – due to resin going in and settling on thin surfaces (interface phenomena)
f. Sensor at safety valve is not allowing the machine to go to HAND Mode. Electrical sensor at safety valve is not allowing the MAIN valve to open in case of HAND because the safety valve is not functioning which is damaged due to intake and settling.
g. Clogging of tube by increase of viscosity of resin thus entering it to small vein of air ventilation pipe.
h. Deposition of carbon particles at sensor.

Remedies/Solutions

In case of bubble in resin while opening resin injection valve

1. Clean the filter after every 4 weeks
2. Give good fluid head. This will ensure that a certain static fluid pressure is maintained on injection side which prevents the air from entering to nozzle prior to resin.
3. Clean the mechanical nozzle portion of die of machine by pulling out the main screw rod which connects/operates the die/nozzle. Re-fix it after words to get smoother operation.
4. Operate the machine in Auto mode.
5. Safety valve pressure determines the opening/closing of safety valve both at die & in tank to allow the resin to go back from die to tank in case pressure exceeds that value.

b. Paper roll alignment/Change of Position/sequence of passage of paper
During the operation of machine, balancing of paper roll was one of the most important problems encountered. In this following three were the most important problems

a. Paper roll alignment
   b. Change of position of paper roll
   c. Sequence of passage of paper above rolls

a. Paper roll alignment

During operation paper rolls tends to misalign under the combined effect of weight and vibration due to motion. These effects tend to misalign the rolls to either directions and create sagging effect in the paper which transmits further in the end product creating defects of overlapping, wrinkles & folds. This alignment defect is removed by balancing the rolls with the help of adjustment rolls located on either side of major rolls alternatively changing their position up &/or below till a uniform optimized position is attained at which paper coming out of rolls is balanced (not undergoing sagging).

b. Change of position of paper roll

During operation the sagging effect is also created in the paper because of change of horizontal position of roll. The roll tends to move towards left or right during operation due to sliding effect created by shear forces generated by pull of paper by Aufwickler and resultant resistance offered by friction between inner surface of paper rolls and outer surface of roll carrier.

This could be avoided by fixing the position of roll on carrier roll by introduction of some fixing mechanisms. In the current unit pressurized air system is integrated for this purpose. This system consists of push pads operated by gasket which in turn is inflated by pressurized air. When pressurized air pushes the pads they push the roll up in such a way that their sliding motion on the surface is restricted, which helps to create sag less continuous paper.

c. Sequence of passage of paper above rolls

Sequence of passage of paper above rolls greatly affects the final quality of film produced. There are two possibilities of passage of paper above rolls.

a. Above the exit side support roll
   b. Below the exit side support roll

   a. Above the exit side support rolls

In this position both papers (one coming from entrance side roll and one coming from exit side roll) are passed above the exit side support roll. The meeting point of two papers is at the epic of exit side support roll. This arrangement has an advantage that it facilitates
smoother production of film and allows time for the homogenization of film after it is developed.

b. Below the exit side support roll

In this arrangement (currently adopted) paper from exit side paper roll is made to pass below the exit side support roll. The meeting point of two papers is at the Aufwickler. This arrangement helps to get uniform film in case when there is sagging in the paper, also avoids paper folding, wrinkling or buckling.

c. Vertical adjustment of roll assembly

Roll assembly is also very important in the operation of machine. Its vertical adjustment plays an important part in the quality of final film produced. During operation it is raised first to its maximum level and then dropped to an optimized level at which film start producing out of machine. It was not quantized initially but was optimized with vertical adjustment assembly with a meter scale which was fitted on vertical stand to get a measure of amount by which roll assembly could be raised or dropped to get a real value of film being produced. This vertical adjustment mechanism can be moved to get an optimized value.

d. Design Changes/Observations:

Following design changes and observations are noted and proposed in machine.

1. Specific weight: 0.85 g/cm$^3$ (this is a mistake in the programming & display of machine and needs to be sent to designer)
2. Minimum level in tank is 1 – 2 mm below the lowest part of nozzle or nozzle is 1 – 2 mm above the bottom of tank. (This helps liquid (resin) flow into die system in two ways: a) helps to damage the vortex formed by vertical spiral of liquid generated by tunnel effect of liquid entering small orifices. b) Helps to damage the horizontal vortex formed by vortex of liquid entering small orifices.
3. Check the viscosity after production
4. Presently a certain roll speed is to be selected & film deposition is checked to be uniform at a certain temperature at which we already know the viscosity.
5. If film deposited is uniform then this is optimum viscosity at that temperature otherwise change roll speed to get uniform film $1 < 5 > m/min$. Repeat the same procedure for 75°C and 100°C
6. Effect of structure change on Resin by repeated heated & its effect on viscosity & film deposition on BESCHICTUNG
7. Scale on process rolls
8. Flow pattern study of resin in die at higher temperature (> 75°C) it tends to go more towards right sides & less to left side, Why?
i. The meeting point of two papers at winder helps to create/induce more air into layer of resin being deposited onto paper. This should be at exit side tension roll. This will help create better matching of two papers. It also wastes a meter of paper.

j. Adjustable speed of rolls is approximately 5 cm from zero level. Procedure is to raise the rolls as near to die as possible & then drop to see that film is uniform with no air bubbles

k. Avoid accumulation of resin on back also

e. Reasons for Delay in Operation of Beichtung

Excessive re-work & unnecessary re-working of the same procedure established earlier.

f. Tabulation of results

Resin Quantity = 3 Kg, 500 Kg for pipes.
Externally heat the resin (438) @ 80°C for 1.5 – 2 hrs (approximately)

<table>
<thead>
<tr>
<th>Speed</th>
<th>Aufwickler</th>
<th>Auf Motor</th>
<th>Temperature</th>
<th>Temperature die</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>0,4</td>
<td>0,2</td>
<td>50</td>
<td>50</td>
<td></td>
<td>Not OK</td>
</tr>
<tr>
<td>0,4</td>
<td>0,2</td>
<td>75</td>
<td>75</td>
<td></td>
<td>Partially OK</td>
</tr>
<tr>
<td>0,4</td>
<td>0,2</td>
<td>100</td>
<td>100</td>
<td></td>
<td>Not OK</td>
</tr>
</tbody>
</table>

At temperatures of 50°C, adhesive forces are dominated
At temperature of 75°C optimum &
At 100°C Cohesive forces are dominant (low viscosity)

Check the viscosity after production as well

Presently, a certain roll speed is to be selected & film deposition is checked to be uniform at a certain temperature at which we already know the viscosity. If film deposited is uniform then this is optimum viscosity at that temperature. Otherwise, change roll speed to get uniform film 1 < 5 > m/min. Repeat the same procedure to get reproducibility.

g. Cautions

a. Take care of pressure of air in the system (the house pressure should have the standardized values and these should be satisfied)
b. Always open the air pressure valve first before starting the machine.
c. Start the machine from heating the resin tank.
d. Observe the sounds of opening of valves and operate the machine step by step by opening the valves.
e. Fear of resin settling, operate the machine on HAND mode. No fear of resin settling, operate the machine on AUTO MODE.
f. Always heat the machine (tank, pipe, die (upper & lower) & motor associated resin container before the actual operation of machine with the pressure of resin.
g. Leave the empty machine heated for about 15 -20 min before putting resin. So, that temperature in all cavities & corners of machine should get uniform.
h. Mark the points on the machine for the adjustments and remembrance for future reference.
i. Use leveler if necessary to accommodate & counter the imbalances in level of rolls.
j. Center the rolls.
k. Use roll tension adjustments for adjusting the tension in the paper for proper film production.
l. Make certain adjustments for controlling the procedure of film production and in line monitoring as this is required for adjusting the paper direction all along the process.

**WARNING!** DONOT start the machine unless all initial conditions of operation are satisfied.

**h. Inferences/Future Work**

a. Study of air absorption mechanism from pneumatic valves to resin (BOX)
b. Carbon based materials (BOX) & their behavior to generate free carbon at high temperature (80 – 120 °C) upon decomposition.
c. Effect of structure change in Resin by repeated heating & its effect on Viscosity & film deposition in BESCHICHTUNG.

**8. Standard Operating Procedure (SOP)**

Standard Operating Procedure of machine is as follows established after workout.

5. First power is turned ON by switching ON the main power from power supply. This release the power to the machine from main power unit.
2. TURN ON the main control unit from a button underneath the unit. (Red)
3. The unit is switched ON from the LCD of the machine and its mains are given time for relaxation, homogenization and normalization. Upon which the main unit releases and get a little time for coming to normal state.
4. Gerät is switched ON, which releases main power to machine. Gerät is a main power unit which consists of Inverter which control & regulates the flow of current to the machine’s other parts.
5. Five minutes are given to Great after opening so that it can get optimum speed and rotation. After 5 minutes, main air valve coming to the machine is opened automatically and observed that it releases air to machine.
6. Tank and dies temperatures are setup. Keep the temperature of pipe $10^\circ$C higher than die temperature in order to ensure smooth flow of resin from pipe to die and allowed time to get to their set states. As soon as temperatures are normalized, machines becomes ready for operation and all signals from and to the machine indicate the further operation of machine. Auftragskopf and Great indications on the machine become clear and it became ready to operate to next step.

7. Auftragskopf is switched ON this allows power to go to machines rotation unit. After this machine is allowed some time to go to normalization.

8. Auftragskopf speed is adjusted as per requirement of the film

9. Aufwickler (primary roller) (driver) is started from LCD, which drives the paper onto it and also force driven roller (secondary roller) to release the paper. This Aufwickler is controlled manually in case of MANUAL MODE of operation. The maximum speed of aufwickler is 80 rpm which is adjusted automatically in case of AUTO MODE as per requirement of film thickness being deposited on paper.

10. As the machine starts, the resin starts coming out from dies and start depositing on paper. As paper progresses, former creates a continuous homogenous layer on the paper based upon hydrophilic and/or hydrophobic character of paper and cohesive &/or adhesive nature of resin towards paper.
7. SECTION 3: Drum winding of carbon fiber for the production of prepreg laminates
a. Principle

The principle of drum winder consists of winding filament fibers around a drum moving with uniform speed. The tension caused by

- Weight of drum
- Brake load on fiber bobbin
- Speed of motor leading towards speed of drum
- Placement of initial (primary), intermediate & support rollers their geometry & configuration
- Length of fiber from bobbin to drum (increased length decrease tension)

is the governing force to wind fibers around the drum. Any alteration in above factors leads towards change in configuration and structure of laminate being wound on the drum. A careful control of these parameters is necessary to achieve good, homogeneous and continuous laminate. Machine is designed in such a way to achieve careful control of above parameters leading towards good quality laminate.

b. Working

Working of machine consists of following steps

a. Check all the hardware of machine for consistency and integrity
b. Start the machine by turning ON its main power located on the left of main control unit.
c. Allow some time for the normalization and homogenization of operations.
d. Click the Start Button on the LCD for operation.
e. Select Mode of operation out of two modes Auto & Hand Mode
Figure 11: Initial startup screen of MIKRSAM® Drum Winder

Figure 12: Auto Mode
c. Consistency check

Initially machine is checked for consistency by comparing ratios of diameters to lengths

\[ 2 \pi r_1 l_1 = 2 \pi r_2 l_2 \]

\[ l_2 = \frac{2 \pi r_1}{2 \pi r_2} l_1 \]

\[ l_2 = \frac{r_1}{r_2} l_1 \]

The experimental values are found to be in good consistency. This test proves that machine exist in good working condition.

d. Modes of Operation

Working of drum winder consist of its operation in two different modes

i. Auto Mode
ii. Manual/Hand Mode

b. Auto Mode
Auto Mode is selected when machine is to be operated for production purpose. It is selected from main display screen of machine. (Figure 1) After selecting auto, input width of tape is given.

1. **Selection of Input Width**

   a. **Method 1**

   In this method, input width is selected by *iteration method*.

   The process is as follows:

   1. Initial width is given by measuring the actual width of fiber strand on the drum. An average of Point A and C is taken. (Fig 15)
   2. This width is given as width of tape on the machine
   3. Machine is started and operated for 04 cycles and checked to exhibit uniformity in fiber placement avoiding gaps/spacing.
   4. If there is no spacing, then this width is set and taken as final input width of fiber/tape
   5. If Spacing occurs, then input width of tape is increased or decreased to get uniform laminate without spacing.

   ![Figure 15: Geometry of fiber traversing on bobbin](image)

   This is chosen based on empirical relation derived earlier by comparing the widths given at input and actual widths existing at output. (Iteration), finally reaching a width which is optimized to get a uniform and homogeneously distributed fibers forming a laminate.
Following empirical relations could be derived from the practice of adjusting the fiber on machine.

Input width = Avg. Width – (0.1 – 0.2) Where
Avg. width =
(Width at drum when fiber is at pt A + Width at drum when fiber is at pt A)/2

Fiber is given initial width same as that of actual width (avg.) and following procedure set above is observed to exhibit spacing or otherwise. Then from the avg. value of width deduced incremental factors are deducted in steps to observe the patterns of laminate till a point is reached where uniform gap/spacing free laminate is achieved.

Formula 2

Input Width = Avg. Width + (0.65 – 0.75)

After observing changes in laminate pattern on drum not being getting rectified, a second approach is adopted in which avg. width is increased incrementally in steps to observe a stage where pattern gets uniform.

b. Method 2

In this method, input width which was selected by measuring the average of actual widths (Pt. A & C) of fiber strand on drum is checked to exhibit a laminate pattern. The objective is to have a pattern with 1-1.5 mm spacing (deliberately). This spacing is desired as it will eliminate itself afterward during hot pressing stage to yield a neat space free uniform prepreg with good properties. (This approach of reverse engineering is found to exhibit much better properties then Method 1)

c. Method 3

In this method input width is selected based on readings taken at different points at fiber on its way to drum from bobbin. The methodology of this method is to trace the pattern fiber traverses and reverse trace the path to reach an optimized value at which fiber is found to have uniform width from which good laminate could be produced. (Fig 15)

Various runs are carried out tracing the motion of fiber from bobbin to drum measuring its width at different points.

Run 1

Brake load = 3 Kg
Tension load (on the lever) = 130 Kg (Maximum position)
Mandrel/drum speed = 1.11 rpm
Carriage speed = 5.785 mm/min

<table>
<thead>
<tr>
<th></th>
<th>Width Position A</th>
<th>Width Position B</th>
<th>Width Position C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entrance</td>
<td>4.72 (free space)</td>
<td>4.62</td>
<td>5.15</td>
</tr>
<tr>
<td>In between primary rolls</td>
<td>4.20 (tension)</td>
<td>2.82</td>
<td>3.47</td>
</tr>
<tr>
<td>Exit from primary rolls</td>
<td>4.30 (free space)</td>
<td>2.81</td>
<td>4.57</td>
</tr>
<tr>
<td>Inside feed rolls</td>
<td>4.11 (tension)</td>
<td>3.91</td>
<td>3.47</td>
</tr>
<tr>
<td>Exit feed rolls</td>
<td>5.10 (free space)</td>
<td>4.87</td>
<td>5.20</td>
</tr>
</tbody>
</table>

From the above tabulations following inferences are clearly evident:

Width undergoes:
- expansion at positions where there is free space (relaxation) (out of rolls)
- contraction at positions where there is close space (tension) (in between rolls)

Generating a zig zag pattern, operating width could be selected by carefully observing the width in between rolls at which laminate pattern on the drum becomes uniform. For example, in Fig 5, when fiber is at position A, on drum it is present from segment at position C i-e 5.20 becomes 5.10. This reduction in thickness creates the possibility in which a uniform width could be achieved without (excessive rework) 

**Run 2**

Brake load = 3 Kg  
Tension = 130 Kg (Maximum position)  
Mandrel/Drum Speed = 1.11 rpm  
Carriage Speed = 5.785 mm/min

<table>
<thead>
<tr>
<th></th>
<th>Width Position A</th>
<th>Width Position B</th>
<th>Width Position C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entrance</td>
<td>4.72 (free space)</td>
<td>4.62</td>
<td>4.92 free</td>
</tr>
<tr>
<td>In between primary rolls</td>
<td>4.20 (tension)</td>
<td>2.82</td>
<td>4.27 tension</td>
</tr>
<tr>
<td>Exit from primary rolls</td>
<td>4.30 (free space)</td>
<td>2.81</td>
<td>3.47</td>
</tr>
<tr>
<td>Inside feed rolls</td>
<td>4.11 (tension)</td>
<td>3.91</td>
<td>4.63 tension</td>
</tr>
<tr>
<td>Exit feed rolls</td>
<td>5.10 (free space)</td>
<td>4.87</td>
<td>5.35 free</td>
</tr>
</tbody>
</table>

The above is second run which yields result of width (operating width) of 5.35 mm instead of 5.20 in above case.

**Run 3**

Brake load = 3 Kg  
Tension = 110 Kg  
Mandrel/Drum Speed = 1.11 rpm  
Carriage Speed = 5.785 mm/min
<table>
<thead>
<tr>
<th></th>
<th>Width Position A</th>
<th>Width Position B</th>
<th>Width Position C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entrance</td>
<td>5.50</td>
<td>5.75</td>
<td>5.85</td>
</tr>
<tr>
<td>In between primary rolls</td>
<td>4.50</td>
<td>4.55</td>
<td>4.50</td>
</tr>
<tr>
<td>Exit from primary rolls</td>
<td>4.90</td>
<td>5.20</td>
<td>4.70</td>
</tr>
<tr>
<td>Inside feed rolls</td>
<td>4.90</td>
<td>5.35</td>
<td>4.72</td>
</tr>
<tr>
<td>Exit feed rolls</td>
<td>5.50</td>
<td>6.27</td>
<td>5.77</td>
</tr>
</tbody>
</table>

This is third run generating a result of width 5.77

d. Conclusion

The selection of final width (operating width) to be given to machine for successful production of laminate is dependent upon random selection of method adopted. There is no cut off method for the selection of fiber width. Any of the above may work depending upon situation, product desired and its quality. In general method 2 is much successful in production of good quality laminate from drum winder.

e. Cautions

1. Machine is very sensitive to initial set speed – follow that!
2. Roll straightening assembly is to be moved 1.5 mm to left to bring it to middle. Otherwise bad patterns will start appearing from the machine.

One reason could be that fiber is squeezed in the very beginning of its path by controlling rollers & then allowed to move free through rest of its path

![Diagram](image)

**Fig 16:** Schematic of spans (regions) of fiber.

Variation/spacing between fibers occurs i.e fibers get thinner. Overlap occurs especially in S₄ because fibers get wider.

3. Do not stop the machine when started for one layer of laminate as this will severely hamper the quality and production capability of laminate produced from
machine. This single factor is very most responsible for the operation of machine as this determines the way in which procedure could be carried to reach the final optimized value.

4. Note the repetition of bad portions & cut/discard those afterwards (if required)
5. Rolls are not inclined. Use inclined rolls i-e inclined to each other at certain angle which creates a position which support that fiber pattern & its motion.
6. Incorporate straight rolls. The curvatured rolls tend to create a geometry in which further motion of fiber is distorted.
7. Use well smoothed straight rolls. Any dips, angles, scratch mark etc. on the straight rolls tends to create distortions on the fiber which tends to continue along and become a source of permanent damage on the laminate.
8. Adjust speed of drum via potentiometer. This helps control the motion of fiber as well as its final deposition on drum to form a laminate.

Suggestions:

Trace out the patterns fiber travels
a) by high speed motion camera
b) liquid penetrate to trace out the pattern of motion
This help great deal in sorting out the detail involved in pattern fiber travel over the rollers and towards drum

ii. Manual/Hand Mode

Hand mode is selected when machine is not to be operated for production purposes, instead is desired to be operated for positioning of jog assembly & motion (rotation) of drum. As shown in figure 3. The carriage assembly and drum can be moved and rotated in manual mode in contingent with knobs present on control panel. Various speed rates can be selected for quick &/or slow movement of carriage assembly & drum

e. Problems encountered during operation

i. Spacing of fiber

Spacing of fiber is an important problem encountered during the operation of machine.

a. The fiber when wound on the drum tends to exhibit spacing between its adjacent layers forming a non-uniform pattern with layers separated from each other which later on severely hamper the final properties.
b. Another important reason for this happening is that the fibers are wound on the bobbin in a pattern which transmits itself to drum forming a structure with spacing
c. The curvature and plain rolls constituting the roll assembly also are placed in such a way that they constitute and finally contribute towards forming an assembly resulting in pattern of spacing in between the layers of fibers and thus in laminates.
ii. Bobbin misalignment from center

Fiber bobbin due to its manufacturer made construction (TEHNOTEX) has a slightly center out construction. This results in inhomogeneous motion of fiber on bobbin which forms an inhomogeneous pattern of laminate. The bobbin is out of center due to its excess construction underneath fibers. The solution to this problem is

a. Manufacturer should be advised to make the centered bobbin. This results in the formation of good laminate with very less trouble and problems.
b. Existing bobbin could be centralized by cutting the excessive portion of bobbin by cutter to make it centralized, which will enhance the probability of fiber moving in center avoiding any chances of problems
c. The bobbin geometry could be reinforced with excessive pads to make an assembly which is centralized and uniform to form structure forming a good laminate.

The fiber tends to slip over the bobbin to left or right due and finally reaching to the position where it becomes more inclined towards one side and less towards other.

The bobbin misalignment is a problem at the production stage of bobbin. Should be reported to manufacturer and rectified at that stage so that final result free of this problem could be devised.

Stage 2

This fiber bobbin misalignment was reported to manufacturer at that stage and then rectified as well to an extent by replacing the thin bobbin with a thick & heavy one which has good properties and structure. This fiber bobbin has only one disadvantage that it results in the slippage of fiber from its edges in soft laces type which results in the destruction of fiber from its edges and deteriorates the whole pattern.

iii. Speed calculation/ratio of diameters

Speed calculation was another big problem in the operation of drum winder. The calculations were carried out to determine the speed of machine before its actual operation. The calculations were based upon comparing the ratios of diameter to lengths and then finding out the optimum speed at which machine could be run safely without problem.

The diameter ratios comparison is adopted by standard formula of comparison, finally leading towards a net shell yielding good results.

iv. Tension adjustment/countering

Another important problem occurring in operation of machine is the adjustment of tension and method to counter it. Too much tension occurs in machine during its
operation and it results in the formation of distorted patterns which consequently disturbs
the final output from machine. The original construction of machine and its associated
assembly is such that it becomes the source of too much tension and this too much tension
distorts the pattern of fiber placement on the drum. The main sources of tension are

a. The construction of fiber bobbin – the construction of fiber bobbin is such
that it creates too much tension on fiber traversing on itself. The bobbin is
made up of number of layers of fibers placed above each other. Each layer
consists of number of turns of fiber placed alongside each other in such a
way that they form a continuous layer. Each layer is placed above each
other forming a structure of bobbin. The style of winding is helix shaped.
This helix shaped winding style, in fact, is a source of tension and creation
of distortion in laminate. The unwinding of fiber from bobbin imparts a
style to its motion which generates tension and this tension is amplified
further when fiber travels on and above the associated roll assembly.
Unwinding pattern from one corner of bobbin to other and vice versa
generates a pull in it.

Remedy: This defect could be removed by

i. Centrally adjusting the bobbin (to some extent)
ii. Adjusting the speed of rotation (to some extent)
iii. Adopting a different style of winding on bobbin (45 degree inclined
style, 30 degree inclined style, 60 degree inclined style) (this
propose to work nicely)
iv. Changing the position of bobbin (increasing or decreasing the
distance between bobbin and first support roll) (This also helps a
great deal in reducing the tension)

1. This may be done by introducing a vertical distance
increasing assembly, which increases the distance fiber
travels before reaching first support roll. This helps in
reducing tension in fiber. However, is subject to following
drawbacks

   a. Assembly is not mechanically balanced, hence
      introduces path curvatures and motion path
      variances.
   b. Vibrations within the assembly and its associated
      network

b. Second reason for this happening is the associated roll assembly which
consists of series of rolls (straight through & curved trough) placed one
after other, above a saddle in such a way that assembly becomes source of
tension. The tension is created by the presence of a lot of rolls. When fiber
travels over and above these rolls, the distance between rolls act as pulling device and generates a lot of tension.

C. Some of the methods suggested & worked out for removal of tension in rolls assembly are: Following two types of formula have been proposed and tested to remove the tension as far as possible.

v. Empirical Formula 1 (input width + factor)

An empirical relation exists between input width from machine and actual width of fiber at the drum which leads towards proper deposition of laminates with no spacing in between fibers. This relation is developed after sorting out careful repeated procedure and observing the behavior of fiber on drum.

Following factors affect the motion of fibers on the drum and its final deposition

- Component of force (generating pull) acting along the fiber coming towards drum
- Number of fibers per strand (i.e. 6K, 12K etc.)
- Weight of drum which finally lead towards tension in machine
- Speed of drum
- Rotational speed of motor rotating the drum, this speed creates pull force

These all factors when applied carefully on the drum yields following two formulas

Input width = average width – (0.1 – 0.2)

Average width = (Width at drum when fiber is at point C + Width at drum when fiber is at point A)/2

(Bobbin not centrally placed)

vi. Empirical Formula 2 (input width + factor)

Input width @ machine = average width of tape + 0.6 – 0.75

Roll gap = 2 mm

(Bobbin centrally placed)

vii. Changing the direction of orientation of fiber on rolls

Another method sorted out after practice is to change the direction of orientation of fiber over rolls. This involves changing the direction from clockwise to anti-clockwise or vice versa. This is devised out of the inference that direction of motion transmits itself further affecting the overall pattern of motion of fiber above rolls to drum.

The direction was changed in following three ways
- Anti-clockwise from below introductory rolls to support rolls and onwards
- Clockwise from below introductory rolls to support rolls and onwards
- Combination of both – following sets were adopted
  
  o Clockwise from bobbin to support rolls – clock clockwise from support to first primary roll – clockwise from first primary to second primary roll – clockwise from second primary roll to intermediate roll – clockwise from intermediate to feed roll
  o Clockwise from bobbin to support rolls – anti clockwise from support to first primary roll – clockwise from first primary to second primary roll – clockwise from second primary roll to intermediate roll – clockwise from intermediate to feed roll
  o **Clockwise from bobbin to support rolls – anti clock wise from support to first primary roll – anti clockwise from first primary to second primary roll – clockwise from second primary roll to intermediate roll – Clockwise from intermediate to feed roll**
  o Clockwise from bobbin to support rolls – anti clock wise from support to first primary roll – anti clockwise from first primary to second primary roll – anti clockwise from second primary roll to intermediate roll – clockwise from intermediate to feed roll
  o Clockwise from bobbin to support rolls – anti clock wise from support to first primary roll – anti clockwise from first primary to second primary roll – anticlockwise from second primary roll to intermediate roll – anticlockwise from intermediate to feed roll.
  
  o Anti clockwise from bobbin to support rolls – clock wise from support to first primary roll – clockwise from first primary to second primary roll – clockwise from second primary roll to intermediate roll – clockwise from Intermediate to feed roll.
  o Anti clockwise from bobbin to support rolls – anti clockwise from support to first primary roll – clockwise from first primary to second primary roll – clockwise from second primary roll to intermediate roll – clockwise from intermediate to feed roll.
  o Anti-clockwise from bobbin to support rolls – anti clockwise from support to first primary roll – anti clockwise from first primary to second primary roll – clockwise from second primary roll to intermediate roll – clockwise from intermediate to feed roll.
  o Anticlockwise from bobbin to support rolls – anti clockwise from support to first primary roll – anti clockwise from first primary to second primary roll – anti clockwise from second primary roll to intermediate roll – clockwise from intermediate to feed roll.
  o Anticlockwise from bobbin to support rolls – anti clockwise from support to first primary roll – anti clockwise from first primary to second primary roll – anti clockwise from second primary roll to intermediate roll – anti clockwise from intermediate to feed roll.
These combinations were tested and tried several times yielding optimized results which can give uniformly spaced laminate. The combination 3 (Italic bold) above is found to exhibit best results. With slight variation in position of rollers an optimized combination is found which yield best properties.

viii. Changing the position of rolls

1. in horizontal direction
2. in vertical direction

Position of roll also plays an important part in the final quality and production capability of machine. The positioning of rolls is a relative factor subject to change with conditions. The best results are achieved with

a. Minimum four rolls and
b. Rolls close to each other towards end
c. Final roll (deposition roll) as near as possible to drum. (This helps in generating final gap less laminate by promoting close deposition of bands to each other)

ix. Roll Control Assembly

The is an assembly which consists of

a. A fixed roll which is rigidly screwed/fixed to one of welded end
b. Moving/adjustable roll which can be moved with the help of screw driven support, which can be moved left or right. It is similar to JACK assembly used in cement mills. The assembly is adjustable to counter the effect of motion of fiber.
Assembly consists of curvature rolls which does not exercise good control on controlling the motion of fiber. As the gap created by the space created within the rolls is wide enough to make the fiber move & still exercise motion. Suggestion is to have straight rolls which can keep the motion of fibers parallel as well as straight. Straight rolls press the borders & sides of fibers & help keep their integrity & shape rather than curved rolls.

x.  **Brake speed adjustment**

Brake speed is also another important factor contributing towards increasing or decreasing the tension in fiber and associated assembly. The brake speed can be controlled by introducing weight system: Weights placed on the brake assembly by the help of lever mechanism, these will create a pull force on fibers making their motion controllable on the drum. Usually tension created is directly proportional to the load placed. More is the load; more will be the tension in the fiber thus exercising better control on the motion of fiber and properties of laminate.

xi.  **Balancing load**

These are the loads which are placed on the brakes for controlling the tension in fibers and making them move without tension on the rolls, resulting in final good laminate. Their effect is exercised more towards when their amount is increased more and this effects final shape, type and spacing of fibers on the laminate.

xii.  **General inference**

Overall little spacing in fibers yields; better laminate at the end because this little spacing then finally overlaps during pressing stage to produce laminate with “no spacing” An optimized 0.75 mm gap produces good results at the end (after roll pressing).

xiii.  **Adjustment by incorporating vertical tension relieving assembly**

(Mentioned at point iv above). This method is adopted based upon methodology that increasing the distance fiber travels allows it to achieve more relaxed state and helps ease out the tension on it, which finally ease out the process of making laminates

f.  **Production of laminates at temperature of**

i.  60°C

Low resin infiltration into fibers, wide spacing of fibers, incomplete wetting of fibers, fiber volume fraction is low, overall bad properties

ii.  65°C

A little improvement in properties by slight deeper infiltration of resin into fibers, slightly less wide spacing of fibers, slight better
Wetting of fibers, yet still incomplete, fiber fraction still remain low, overall bad properties.

iii. 70°C (an optimized temperature is 70°C)

This proves out to be best optimum temperature for the production of laminates. This gives
a. very good infiltration of resin in fibers
b. good spacing of fibers, producing good gap free laminate
c. Good wetting of fibers, thus producing very good laminate which is nicely filled with resin.
d. Good fiber volume fraction ensuring high amount of fibers per unit volume thus producing good quality laminate.
e. Overall properties of laminate are very good.

g. Reason for Resin de-adhesion on drum winder

a) Reverse tension on drum winder
b) Winding of fiber on drum winder after 3-4 days, which might have caused any aging effect on resin to lose it adhesion with paper

Suggestion:

a) Put freshly made resin on drum winder & start the process
b) Decrease temperature in BESCHICHTIGUNG to increase the viscosity & get thicker film expected to have higher adhesion with paper & cohesion in between itself.

h. Checkout of fiber volume fraction of composites

This is a test carried out to check the percentage of fiber volume fraction of composites.
The procedure adopted is according to ASTM D2584 / ISO 527-1 /DIN EN 60

Procedure is as follows: This method determines the mass of the resin by determining the ignition loss of a cured polymer composite. To achieve this specimen of known mass is heated until the resin matrix is oxidized and converted to volatile materials. The ash is removed and the residual, assumed to be the fiber reinforcement is weighed. The fiber volume fraction is determined by knowing accurate values for the density of the fiber and the composites. Any filler not oxidized with the matrix will affect the calculation of fiber volume fraction. Similarly any volatiles such as water or residual solvent will cause errors unless they are small enough to be ignored.

The calculated by measuring the weight of the remaining fibers and calculating the knowing the density of the fibers and the weight of the original sample. Accuracy of this
method is determined by the accuracy of the weight and density measurements of the composite and the undigested fibre.

\[
V_f = 100 \times \frac{M_f \rho_c}{M_c \rho_f}
\]

where:

- \( M_f \) is the mass of the fibres
- \( M_c \) is the mass of the composite
- \( \rho_c \) is the density of the composite
- \( \rho_f \) is the density of the fibres
8 Conclusions

The whole exercise of prepreg development process involving above mentioned equipment and processes (partly existent earlier and partly developed) concludes that same could be utilized for the efficient production of prepregs. Further optimization could lead towards production of composite prepregs at large scale.
References:

[1] Email communication: Mr. Dimitri, MIKROSAM