SpliceLab 2.0
User's Guide
For FSM-100 and LZM-100

Fiber Taper software
Version 8.0

Tech Support
800.866.3602

Read this instruction manual carefully before utilizing this software.

Keep this manual in a safe place.

Contents in this manual may change without prior notice due to improvements in product features and specifications.

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Table of Contents

1. Introduction

Splicing in a research and development environment often requires tools that are not present in the splicer firmware or are time-consuming to access through the standard splicer menus. To address these needs, AFL developed the Splice Lab environment. Splice Lab is a PC-based system that expands the capabilities of the FSM-100 and LZM-100 series splicers. Splice Lab consists of a group of files for different functions and applications

This tapering software is designed to control and monitor the tapering of optical fibers utilizing the FSM100, FSM100+, and LZM100 series splicers. It allows for the control of taper lengths, fiber and motor positions, absolute and relative heating power, and motor combinations. The software has five control functions: Initiate, Taper, Measure, Stop, and Reset. The software application and process parameters define the production of a Single Optical Fiber taper utilizing either PC or Manual Control.

1.1. General Features of the Software

- Creating, measuring, image archiving fiber tapers using FSM100 Fujikura fusion splicers series and LZM-100 CO_2 laser glass processor
- Ease to design a fiber taper geometry and define machine parameters to repeat the desired process
- Capabilities to drive individual motors, initiate and stop the arc or lase, and control the heat power
- Geometry tools that use embedded algorithms to determine taper diameter and distance between any two points of interest
- Enhanced rotation control for overcoming the effect of gravity or uneven heating during the taper
- Load-cell tension monitoring
- Real time warm taper image (WTI) monitoring and control
- One software application for 5 machine types, FSM-100M, FSM-100P, FSM-100M+, FSM-100P+, and LZM-100
- One software application for the most common PC systems, such as Windows XP, Windows 7, and Windows 8, 32 and 64 bit platforms, and MS Office 2003. 2007, 2010, 2013.

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1.2. Tapering Theory and Technology

1.2.1 General Taper Theory and Geometry

Tapers are widely used in many different fiber based components and applications, such as multi-fiber combiners and mode-field-adapters in the fiber laser industry, probes and sensors in biotechnology, and couplers and wavelength multiplexers in telecom. Depending on the application, the fiber used for tapering can be single mode, a few modes, or multi-mode. The fiber can range in diameter from less than 40 um to over 2.5 mm. Common terms used to describe a simple taper are illustrated in Figure 1-1.

The taper ratio, R, is the ratio of the original fiber diameter to the taper waist diameter. In most applications can be from 0.1 to 10, or even wider. For a classic taper, the waist is thinner than the original fiber (R>1). However, some applications require sweeping the fiber thru the heating area without changing fiber diameter for thermal core expansion or cladding surface annealing with R = 1. Situations requiring an R < 1 include but are not limited to manufacturing mode field (or NA) expanders, elongated ball-lenses, and end-capping.

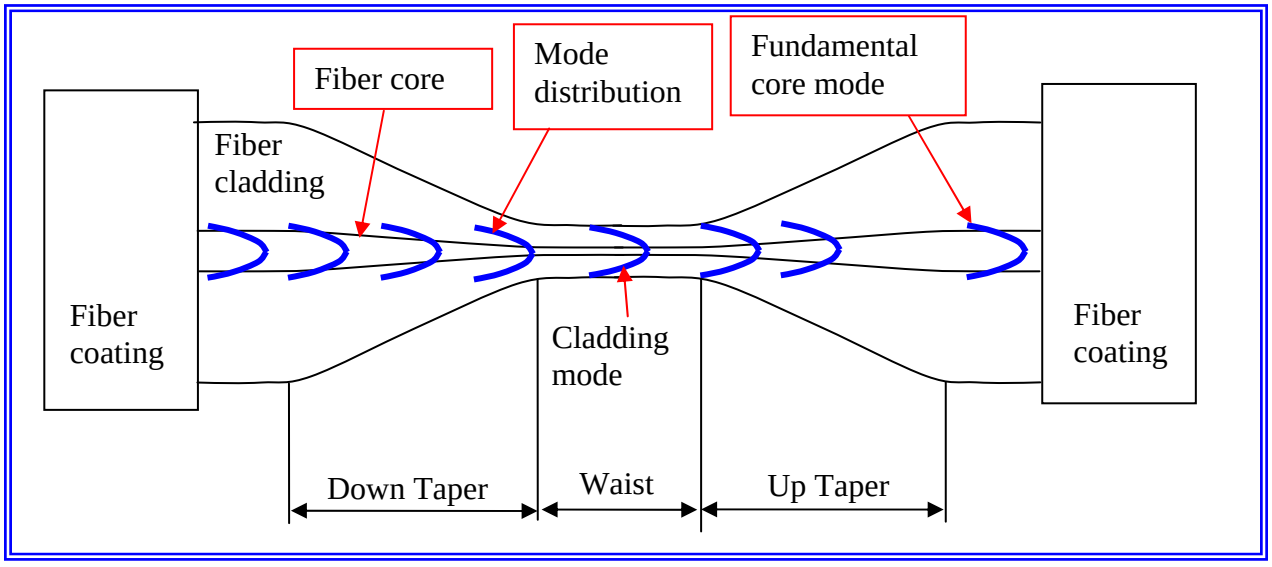


Figure 1.1 Geometry of a fiber optic taper.

1.2.2 Adiabatic Tapering

Adiabatic tapers are tapers whose shape does not change the fundamental mode in the fiber. The optical energy carried by the fundamental mode is virtually unchanged –and the loss due to the taper is very low. This type of taper is extremely important in many applications, especially in high power fiber lasers. The taper illustrated in Figure 1-1 is adiabatic. Although the core mode of the original fiber is converted to a cladding mode at the waist by the down-taper structure, this mode can be completely converted back to its fundamental core mode by the correct up-taper design. Both down-taper and up-taper need to be very smooth and the maximum taper angle must be kept below a certain threshold at any location along the entire taper. This taper angle threshold is normally referred to as the adiabatic taper angle. For SMF28, the adiabatic taper angle is 0.35

degrees. However, the adiabatic taper angle varies with different fiber designs. It can usually be determined experimentally for a particular fiber through loss measurements.

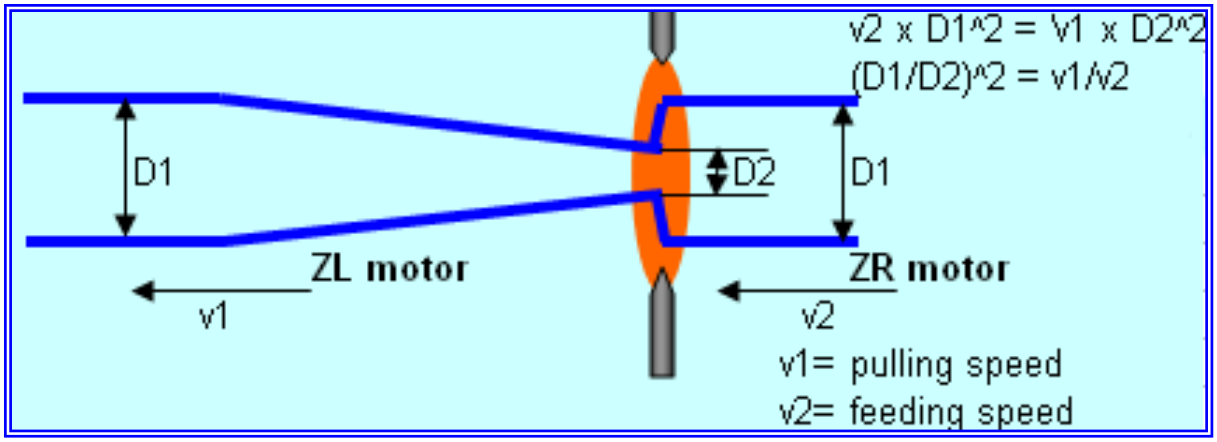


Figure 1.2 Principle for speed control to make a long taper.

For making a long taper, such as an adiabatic taper, the fiber can be pulled from one side of the heat zone and fed from the opposite side. The feeding and pulling directions are the same. But feeding and pulling speed are different, which controls the taper ratio. Due to the material conservation shown in Eq. (1), the glass fed into the heat zone should be equal to the glass pulled out from the heat zone. Based on the definitions shown in Fig.1.2, we have the following equation to determine the relation between pulling and feeding speeds from the desired taper ratio at any location of tapering process in Eq. (2):

$$\pi D_1^2 V_2 = \pi D_2^2 V_1 \qquad (1)$$

$$(D_1 / D_2)^2 = V_1 / V_2 \qquad (2)$$

A linear section for either down-taper or up-taper gives the shortest taper length for any desired adiabatic angle. Therefore, it is optimum for adiabatic tapers. Obtaining a linear taper region requires solving a complicated analytic equation with integration. The PC software provides linear and sine taper shapes only. For any additional special taper shape requirements, please contact AFL.

2. Installation

2.1. Installation Instructions

The current version of SpliceLab is software to control FSM-100 and LZM-100 splicers. The splicer should have installed with firmware version higher than or equal to 01.019 for the FSM-100 and 01.001 for the LZM-100.

The basic steps for the software installation and operation are listed below:

1. Install the latest Data Communication software from the CD-ROM.
2. Connect the PC to the splicer with the USB cable.
3. If USB cable is connected, a message of "Found New Hardware" may be shown on the right bottom of PC screen, and "Found New Hardware Wizard" dialog window may open.
4. Follow the instructions of the "Found New Hardware Wizard". You should select "No, not this time" to the question of "Can Windows connect to Windows Update to search for software?". In the next page, select "Install from a list or specific location". In the next page, select "Do not search, I will choose driver to install". And in the next page, select "FJK-SY-052". Click "Next" and wait for the automatic installation. It may take a while for some PCs. When complete, the PC is ready to run SpliceLab.
5. Open the Data Communication software. Verify the installation was successful, by viewing a live video image from the splicer connected. Remember to close Data Communication program before opening the Excel applications.
6. Install to the PC, the Excel driver for SpliceLab your PC platform (32 bit or 64 bit).
7. The Splicer should always be in "READY" mode to run the SpliceLab applications.
8. Test-run the Taper software by opening the file and visually watch for any errors to occur while the software communicates with the splicer
9. In case errors are observed, please read the PDF file "FSM-100 SpliceLab training" to resolve the problems.
10. If there are problems which you cannot resolve, please save the Excel file and e-mail it back to AFL for analysis.

3. Launching Splice Lab

Important Note: Before launching Splice Lab, verify that the splicer is connected to the PC using the USB cable, and also verify that the splicer is in the "READY" state. If this is not done, a communication error will occur.

Executing SpliceLab files will start the macros embedded in the Excel files. Depending on the version of MS Office you are using, you may need to enable the Macros for your version of Excel. Adjust the security level to "middle" or "low" in order to enable macros.

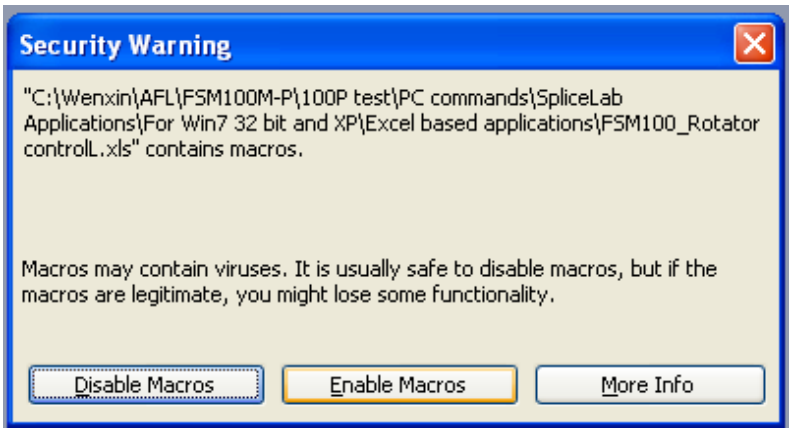


Figure 3.1: *Tune the security level to "middle" or "low"* and c*lick* "*enable macros*" for Excel 2003.

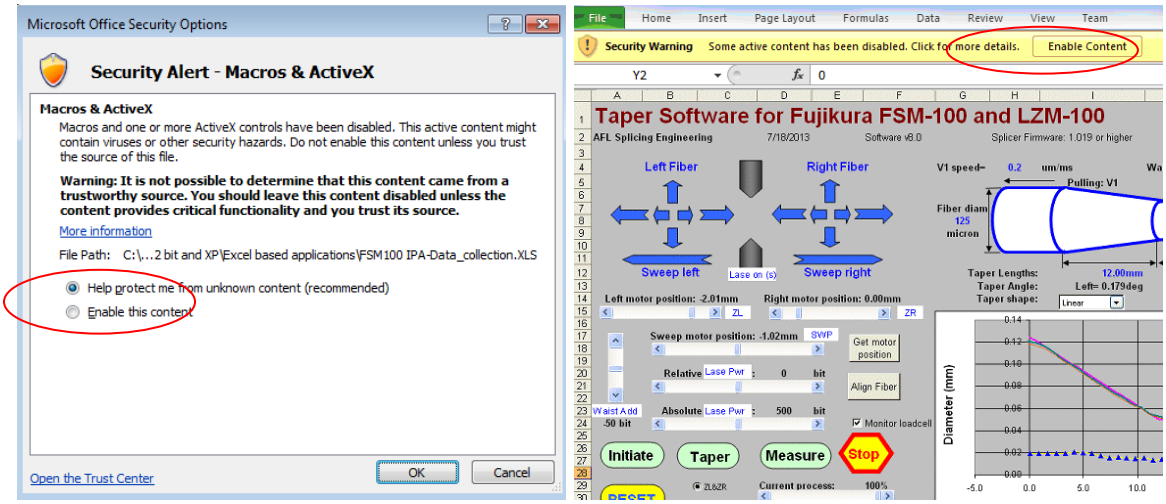


Figure 3.2: *Tune the security level to "middle" or "low"* and c*lick* "*enable macros*" for Excel 2007 and 2010.

For more information on changing the security level, please read the following online instructions by Microsoft.

For Office 2003, please read

Enable macros to run for Excel 2003

For Office 2007, please read

Change macro security in Excel 2007

For Office 2010, please read

Change macro security in Excel 2010

Figure 3.3: Online instructions by Microsoft for changing the security level

Immediately after launching the Excel file, the background macro will communicate with the splicer to determine the "machine type" (splicer model) information as well as the serial number. If you see the correct serial number displayed on the top-right of the "Control" page of the taper GUI, the communication between the splicer and the PC has been established successfully.

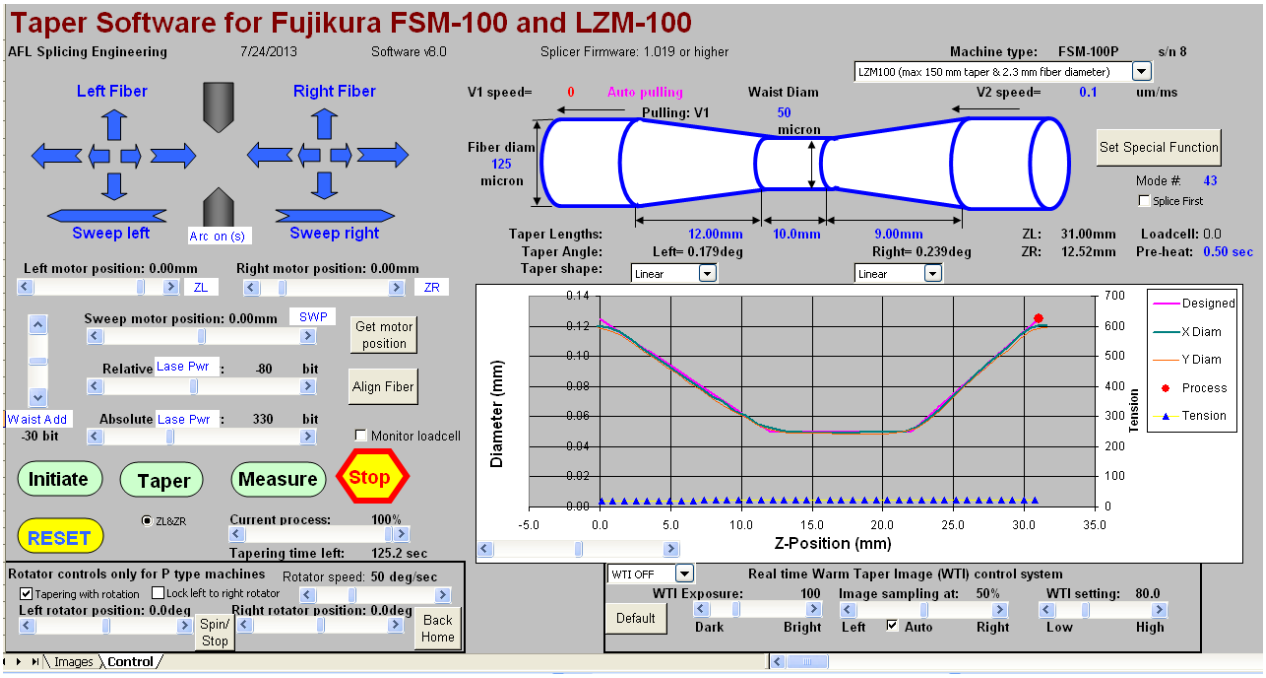


Figure 3.4: Control page and splicer information on the top right

The machine type is automatically set by the taper software at the time of file launching. However, if you would like to manually select a different machine type, you can use the drop-down box on the top-right of the GUI. Please be aware that if the selected machine type is not the actual machine type to which you are connected, the motor travel range, the process instruction, and the waning texts will all be incorrect. Your process may not execute properly.

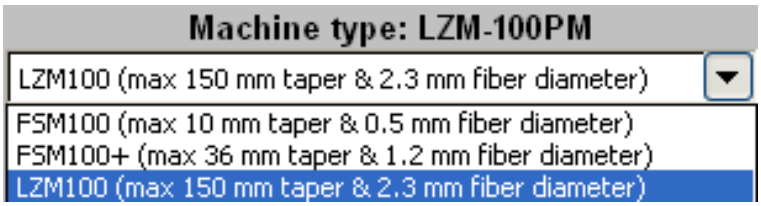


Figure 3.5: Drop-down box for the machine type selection on the top right

Figure 3.6: Connection info at the first time launching

Important Note: Sometimes the ***Connection error: 0*** in Fig 3.6 is shown at your first time launching the taper software, you need only click OK and continue with your work. If you encounter a consistent communication error when you launch the Excel Taper application (and the splicer is connected and in the "***READY***" state), it may be necessary to troubleshoot the communications error. The best to do this is by using the ***Data Connection*** software included on the Fujikura CD ROM that was supplied with your splicer. (This is the software package that enables splicer firmware upgrading from the internet, capture of screen images, and other function.)

Additional Note #1: In order to use ***Data Connection*** software, you must first completely close Excel. You must not only close the Excel Taper application, but also any other Excel files that are open on the PC. Otherwise Excel and the ***Data Connection*** software will have a conflict competing for use of the USB port. After closing Excel, launch the ***Data Connection*** software. Confirm that communications has been established by using some of the functionality of the ***Data Connection*** software such as starting live video, clicking on "***X/Y***" to ensure that the ***X/Y*** command changes the display image on the splicer, confirming that clicking "***RESET***" on the ***Data Connection*** resets the splicer, etc. If the ***Data Connection*** software successfully communicates with the splicer, completely close that software (to avoid a communications conflict), and re-open the Excel Taper software and try again. If the ***Data Connection*** software does not properly communicate with the splicer, consult with your AFL or Fujikura service support representative.

Additional Note #2: When using the Excel taper software, other applications that might compete with the Excel taper software for use of the USB port to communicate with the splicer (such as the ***Data Connection*** software application) must be closed. However, you may have multiple Excel files open simultaneously.

4. Machine Selection and Taper Dimensions

4.1. Machine Selection

The type of splicer utilized determines the maximum taper length and fiber diameter that is achievable. The three types of splicers available for tapering are the FSM-100, FSM-100+, and LZM-100. They can be selected from the "***Machine type selection***" drop down list.

For FSM-100 machines, the maximum taper length can only be achieved using a ***Sweep/ZR***-motor combination (to be discussed below). Using the ***ZL/ZR*** combination will result in a higher quality taper, but will only produce half of the maximum taper length listed below due to the shorter travel of the Z-motors as compared to the ***Sweep*** motor. The LZM-100 does not have sweep motors. When the sweep function is selected for LZM-100, the ***ZL*** and ***ZR*** motors will move in a synchronized motion.

Splicer	Max Taper Length (mm)	Max Fiber Diameter (mm)
FSM-100	10	0.5
FSM-100+	36	1.2
LZP-100	150	2.3

Table 4.1 Theoretical maximum taper length of different machine types

The maximum taper length listed in Table 4.1 is the maximum taper length can be made at a lower taper ratio. If the requirement on taper ratio is larger, the taper length will be reduced significantly as illustrated in Sec 4.3.

4.2. Taper Dimensions

The adjustable dimensions used for tapering include fiber diameter, waist diameter, and taper lengths. These values (indicated in Blue) can be adjusted by manually typing in the desired values. Any values in black or pink cannot be changed by manually typing in new values.

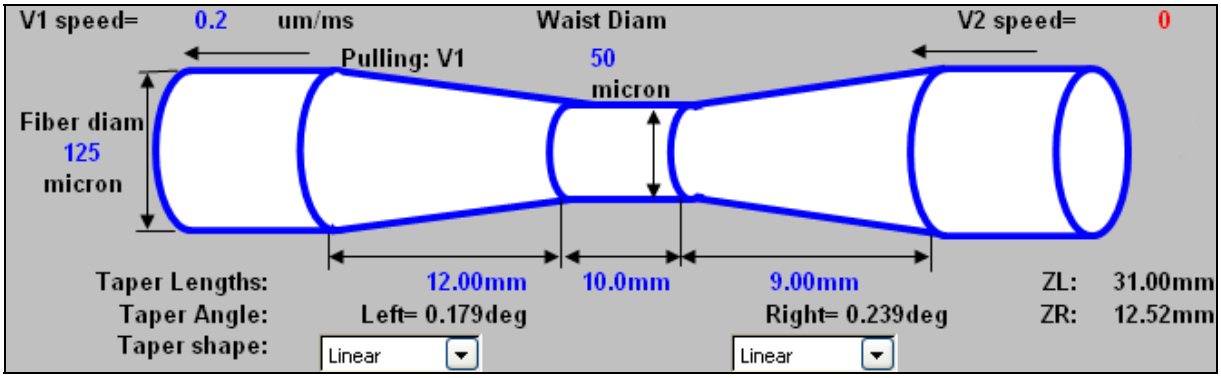
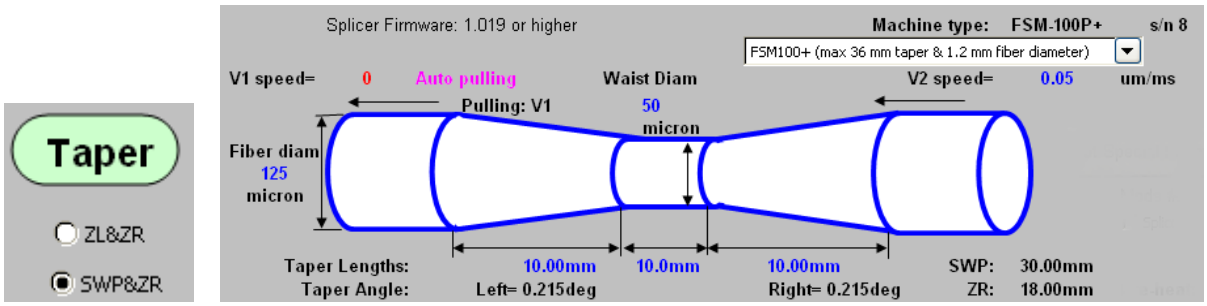


Figure 4.1. Values in blue are editable. Red values represent warnings.

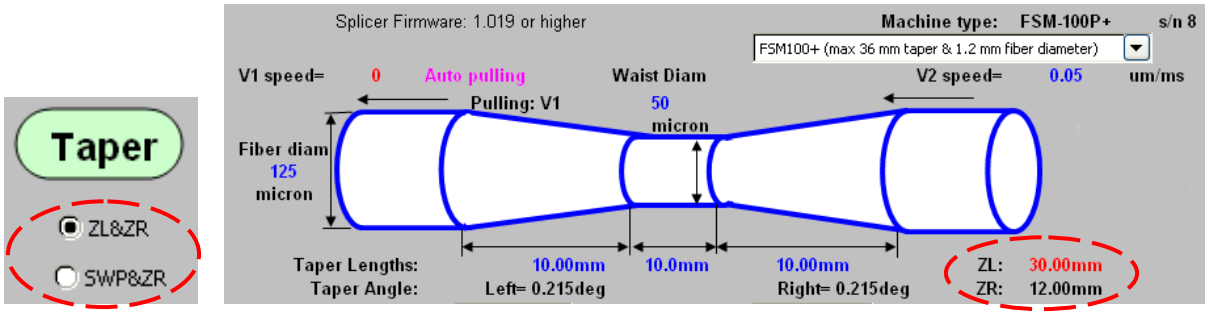
Additional displayed parameters in the fiber dimension section of the software interface include Taper Angle, ZL travel length, and ZR travel length. The values displayed are calculated based on the user defined fiber taper dimensions. The Taper Angle values will be displayed in red if the dimensions could create significant loss provided the fiber is SMF28. For all other fiber types, you may determine the threshold taper angle by experiment. The taper process will still work properly with the red taper angle displayed.

4.3. Z motor travel length

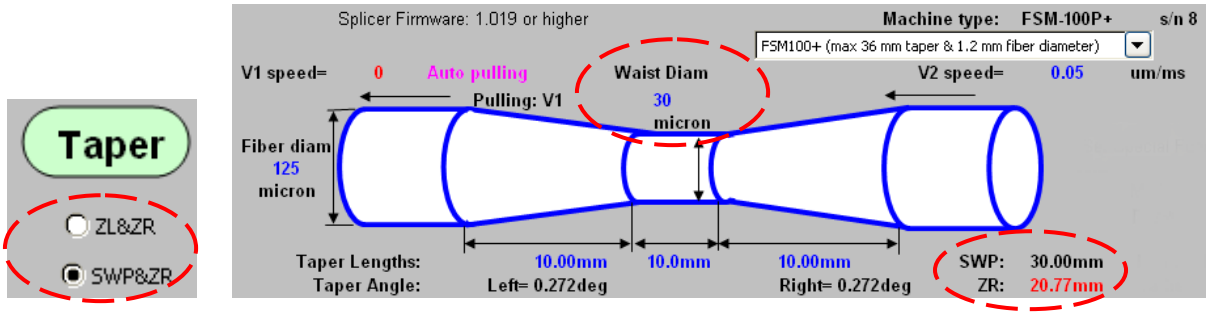
The ***ZL***, ***ZR***, and ***Sweep*** motor actual travel lengths are shown based on the selection of taper method. They will be displayed in red if the length is not achievable by the selected taper method or the machine type.



(a) Tapering with *Sweep* and *ZR* motor at taper ratio 2.5



(b) Tapering with *ZL* and *ZR* motor at taper ratio 2.5



(c) Tapering with *Sweep* and *ZR* motor at taper ratio 4.1

Figure 4.2. Example of taper dimension 10 x 10 x 10 mm for its down-taper, waist, and up-taper using an FSM-100+ machine. The red number indicates an inappropriate taper method which is not capable by this machine.

When a red number occurs for the motor travel length, you have to modify your taper design and method, or change your machine type. The taper process will not work properly with red motor lengths, since there is not enough travel space.

4.4. Taper ratio

The definition of taper ratio in the User's Manual is

Taper ratio = Fiber diameter / Waist diameter

The maximum one pass taper ratio is 10 for FSM-100 and standard LZM-100. When your designed taper ratio is higher than 10, the number of ***Waist Diam***. will display in red. This will also trigger the red colors for motor travel length and speed. One example is shown in the following chart.

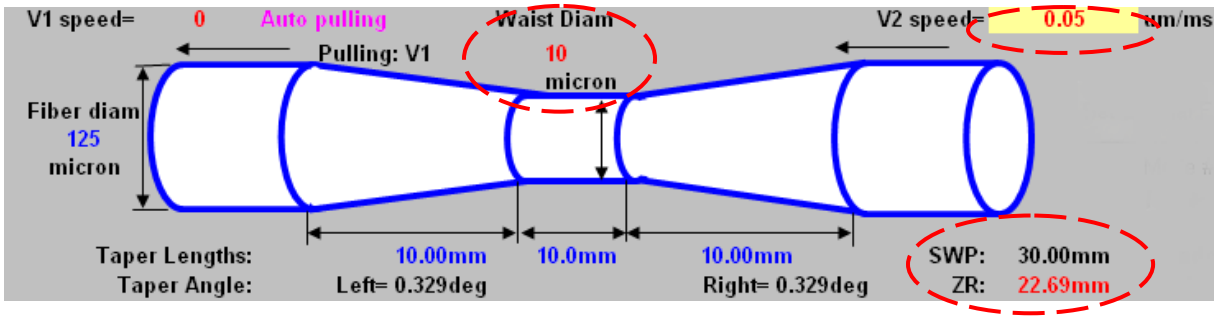


Figure 4.3. Too large taper ratio in design. Red values represent warnings.

4.5. Taper shape

The taper shape is selectable for the down-taper and up-taper individually. Currently there are only two selections, linear or sine curve. For any additional special taper shapes, please contact AFL Splicing Engineering.

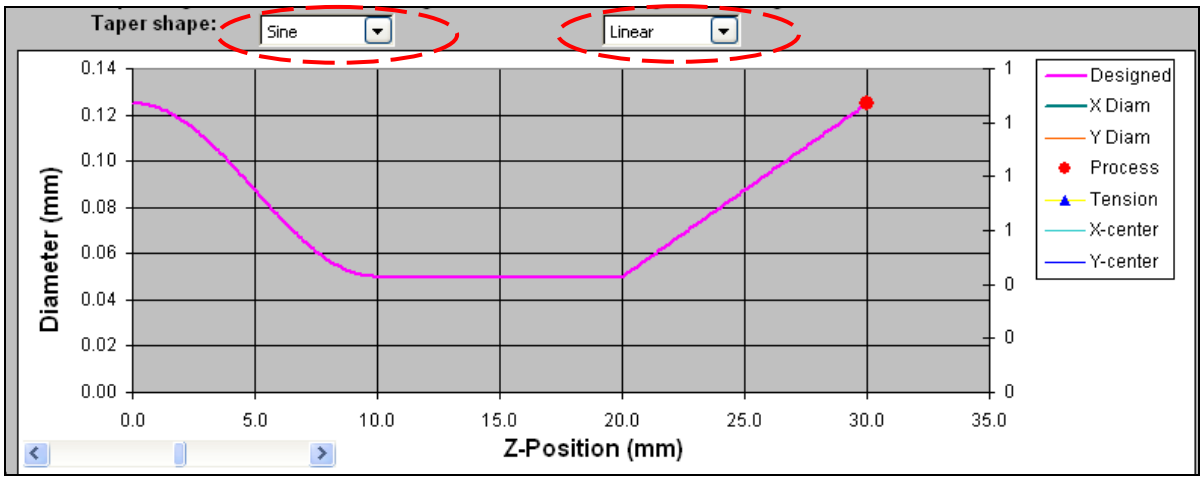


Figure 4.4. Taper shape selection for down-taper and up-taper individually.

5. Taper Process Control Parameters

5.1. Taper speed

The pulling speed V1 and feeding speed V2 are normally applied simultaneously during the tapering process. The speed difference is controlled by the software, which in turn provides your desired taper shape. V1 and V2 speed are adjustable. However, only one of them can be zero. If V1 is set to zero and V2 (feeding) speed is non-zero, it is auto pulling mode where the pulling speed (V1) is calculated by the taper program based on your taper geometry design. On the other hand, if V2 is set to zero and V1 (pulling) speed is non-zero, it is auto feeding mode where the feeding speed (V2) is calculated in real time during the tapering based on your taper geometry design. It is not allowed that both V1 and V2 are set to zero or both of them are non-zero. The allowed speed range for V1 and V2 are 0.01 um/ms minimum and 1 um/ms maximum. When V1 or V2 is out of range, the speed number will be displayed in red. Moreover, since the V1 and V2 are also related by the taper ratio, if a V1 value would cause V2 value out of range, and vice versa, the speed number will be displayed in red with yellow background. Whenever this happens, a new speed value must be selected. Some examples are shown in the figures below.

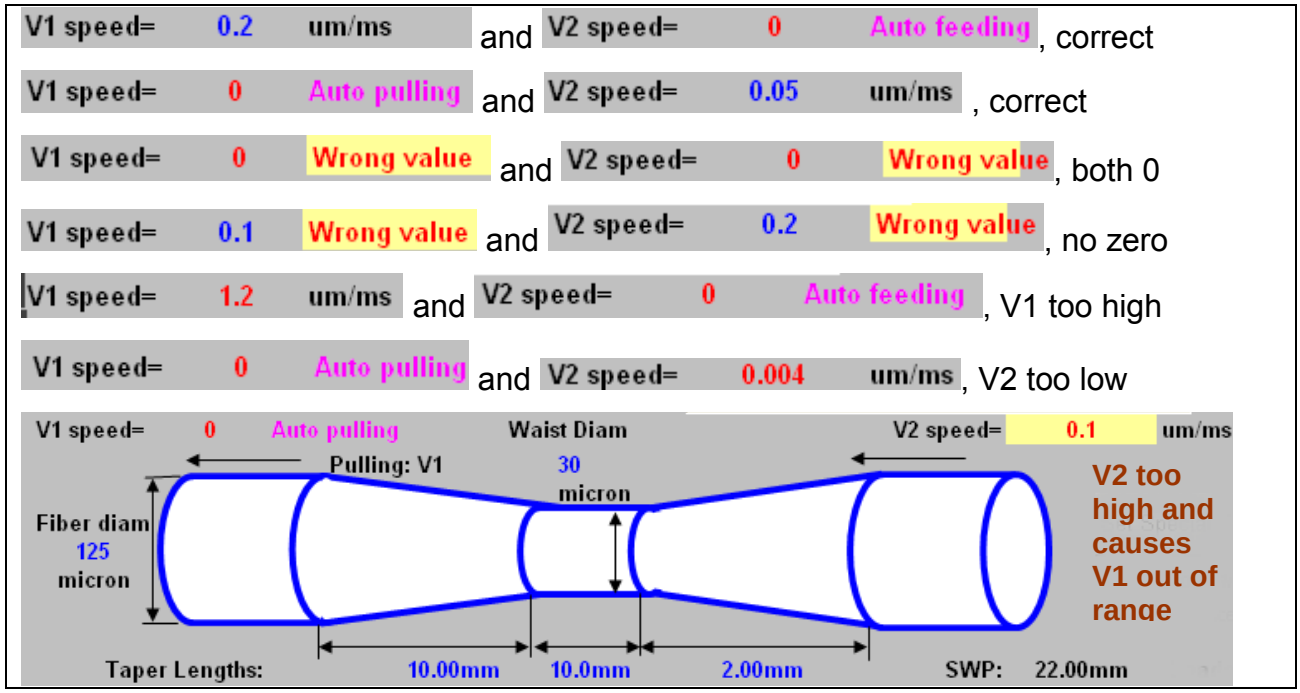


Figure 5.1. Some examples showing the V1 and V2 value selections and the GUI's response.

5.2. Mode Selection

A tapering process can either be performed by this PC program or by the splicer alone without a PC connection. After creating a taper design using this PC program, the process parameters can be transfer to any one of the 300 splice modes in the splicer. At production lines, operators can then repeat this process using the splicer only. Further more, by checking or un-checking the ***Splice First*** box you can tell splicer either to make a splice before tapering, or tapering without splicing. To load a taper mode onto the splicer, first make any desired adjustments to the tapering length, fiber diameter, and waist diameter values (indicated in Blue). And then enter a valid mode number (1 to 300) and click the "Set Special Function" button. This will automatically prepare the desired taper program and send it to the splicer (for details read Chapter 7).

For example, to load this program onto the splicer mode 22, you need to enter in **22** right to ***Mode*** #.

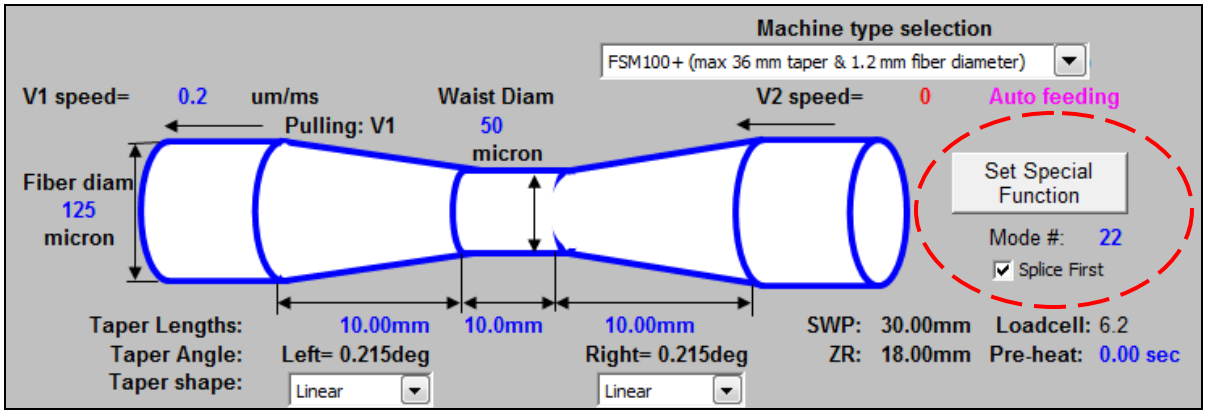


Figure 5.2. One taper example to be transferred to Splicer mode 22

If splicing is required prior to tapering, the ***Splice First*** box should be selected. To load the program onto the splicer, click the ***Set Special Function*** button in the tapering software. This will prompt the user to overwrite all parameters in the selected position (see below). Click "Yes" and the tapering program will be downloaded onto the splicer.

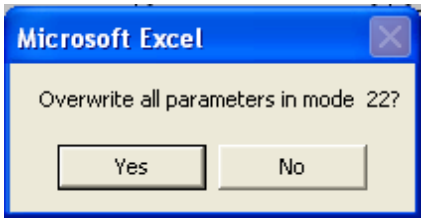
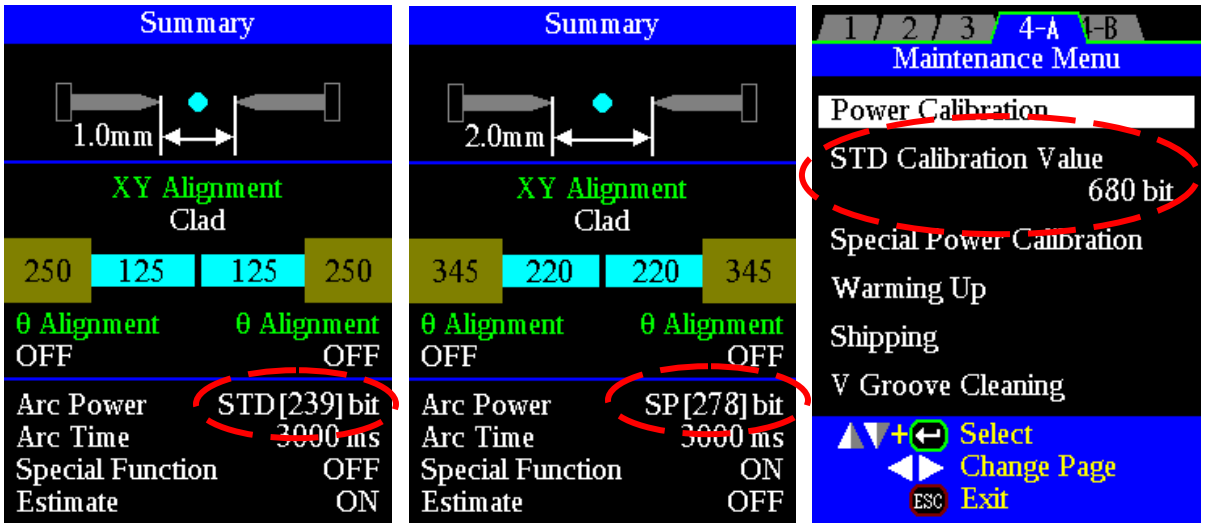


Figure 5.3. Conformation for overwriting all parameters in mode 22

In this case the taper is always processed with PC control, the mode can be any number and the ***Set Special Function*** button is not necessary to be clicked.

5.3. Power calibration

A power calibration has to be performed in order to obtain the best absolute arc / lase power for taper manufacturing. For standard fiber size (125um clad), this can be accomplished by a ***Standard Arc Calibration (STD)***. For non-standard fiber sizes (not 125um clad) on FSM-100 machine types, a ***Special arc calibration (SP)*** is needed. Since CO_2 laser heating is not fiber diameter sensitive, LZM-100 provides only ***Standard Power Calibration (STD)***. For a procedure of making such power calibrations, please read the User's Instructions for the machine you are using. The calibrated power value can be found in the mode for the calibration with FSM-100 or the ***Maintenance Menu*** with LZM-100 as shown in Figure 5.4.



(a) FSM-100 STD arc cal **(b) FSM-100 SP arc cal** **(c) LZM-100 power cal**

Figure 5.4. Examples of power calibrations for different machine types

When arc calibration is complete with FSM-100 machines, navigate to the Edit Splice Mode tab (5-β) while paging thru to locate SP [value] bit and obtain the absolute arc power bit value for taper manufacturing process. For LZM-100 machine, the calibrated value can be easily obtained on the page of ***Maintenance Menu***. This value will be needed in the next section.

5.4. Power setting for taper process

The actual heat (arc / lase) power applied to fiber during tapering process is the sum of ***Absolute Power***, ***Relative Power***, and ***Waist Add Power***. The value of the ***Absolute Power*** should be set to the same as the [Calibrated Power] by ***Power Calibration***. You need to set this value manually, since the software does not know your power calibration method (STD or SP) and the mode used for the calibration. To input the value, you can either use the slide bar by dragging or clicking the side-arrows, or directly type the value into the white ***Arc Power*** (***Lase Pwr*** for LZM-100) label box and press return on PC keyboard.

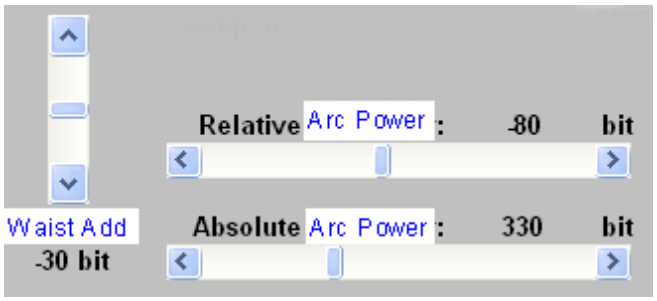


Figure 5.5. Power controls for taper process

For most tapering processes, a much lower power should be used compared to splicing should beused. As a general thumb of rule, the tapering power should be 75% of splicing power for the same fiber type. For example, the calibrated power is 330 bit. Then the suggested taper power should be around 330 x 75% ≈ 250 bit. This means that the inputted Relative Power should be 250 – 330 = -80 bit.

For a small waist, the heating power often needs to be further reduced for arc discharge machines (FSM-100) to prevent fiber from melting OR the heating power needs to be further increased at the small waist for CO_2 laser beam heating (LZM-100) to get enough absorption. So, the ***Waist Add Power*** parameter is used for this type of waist power adjustment. It can either be positive or negative values. It will be gradually applied to the fiber at down taper and up-taper region instead of applying abruptly right at the waist. A typical chart of the power profiles during the tapering process is shown below.

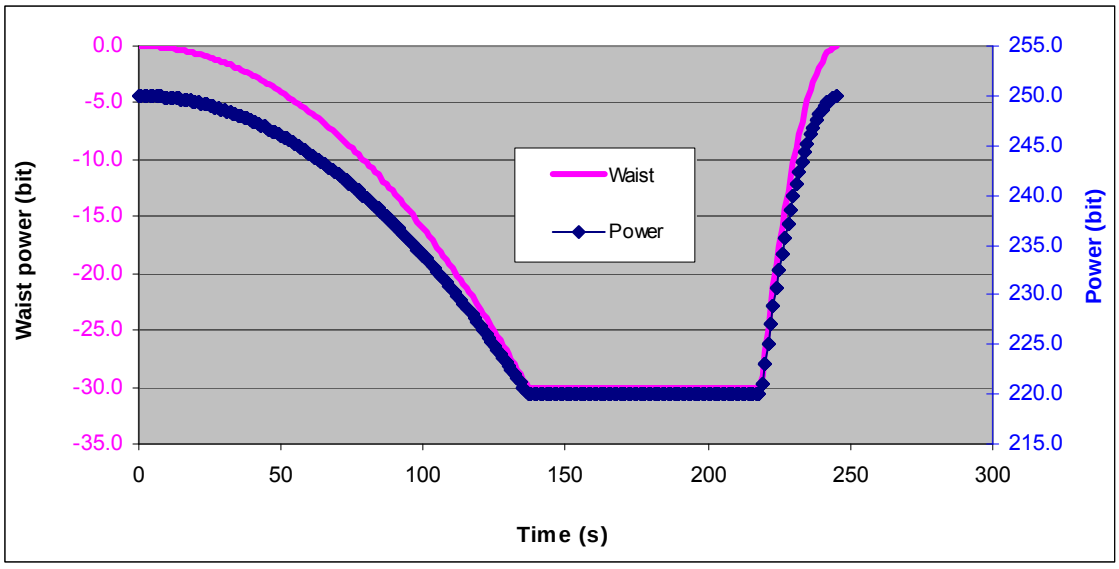


Figure 5.6. Power variation profile for the power setting shown in Fig. 5.5. The total power (blue curve) gradually drops from 250 bit to 220 bit at down-taper region and then keeps constant of 220 bit in the waist.

Important note for total power for arc discharge machines: The arc discharge has a lower current threshold. If the power setting is below the threshold the arc discharge will be unstable and a noise can be heard during the discharge. This lower power threshold for FSM-100 machines is 180 bit. So, the total power, i.e. ***Absolute Power + Relative***

Power + Waist Add Power, should never be lower than 180 bit. If the power is still too high at 180 bit, the value of electrode height should be adjusted to a negative value to create an offset between the arc center and the fiber axis. For LZM-100, there is no suchissue, since the laser power can be continuously adjusted from 1 bit to 1000 bit.

5.5. Preheating and tension monitoring for taper process

For a large diameter fiber, preheating before tapering is necessary to soften the glass. For example, a 1 mm diameter fiber normally needs 5 sec preheating, while 2 mm fiber may need 25 sec of preheating. The preheating power is the same as the tapering power, i.e., ***Absolute Power + Relative Power***.

The preheating value can also be negative. For this case the heating power will be turn on after the starting of the tapering process. This is useful method for tapering small diameter fiber with some tension applied to the fiber.

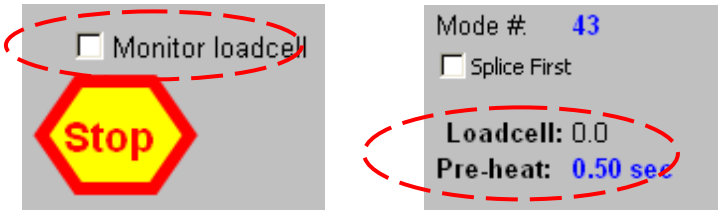


Figure 5.7. Controls for preheating and tension monitoring

The tension monitoring function is only available for LZM-100 CO_2 laser splicer. To activate the tension monitoring, the check box ***Monitor loadcell*** has to be checked. During the tapering process, the tension value will be display on the process chart. If the current fiber tension is to be measured (before or after the tapering process), the ***Get motor position*** button must be clicked and the current tension value will be shown as the ***Loadcell*** value.

5.6. Rotation speed for tapering

The rotator control settings are only functional for splicers which have one or two rotators installed, such as FSM-100P, FSM-100P+, and LZM-100. If no rotator is found on your machine, a message "**No rotator found for this function**" will be displayed. If you are sure there is a rotator on your splicer, please close the Excel file and reopen it again to let software re-communicate with your splicer.

Rotation during tapering is important to evenly heat non-solid or holey materials. Generally speaking, a higher rotation speed will yield a more evenly heat. The maximum rotation speed is 50 deg/sec for FSM-100 and 150 deg/sec for LZM-100. To rotate during tapering, the ***Tapering with rotation*** check-box needs to be checked. After tapering, the rotator will go back to the home position automatically when the wind protection cover is opened. You can also manually move the rotators to the home position by clicking the button ***Back Home***. The ***Rotator Speed*** slide-bar can be dragged for speed adjustment or clicked on the side-arrows for a fine adjustment.

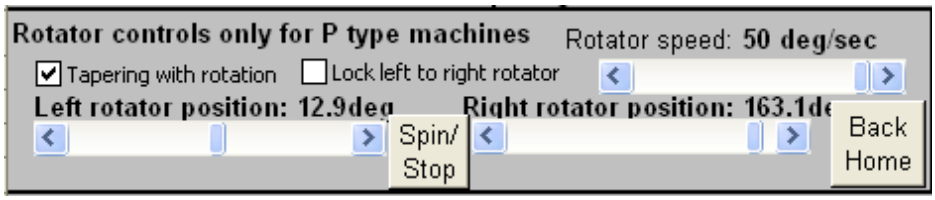


Figure 5.8. Controls for rotation and spin

For tapering, the rotation function has already been designed in the software if the ***Tapering with rotation*** is checked. If you would like to do a manual rotation to check the straightness of the taper, you need to click the ***Spin/Stop*** button. The rotators will be stopped if the ***Spin/Stop*** button is clicked again during rotation. If the ***Lock left to right rotator*** is not checked, the ***Spin/Stop*** button will only control the right-side rotator.

5.7. Warm taper image (WTI) control

The entire heating power curve described in Sec. 5.4 is determined by the taper parameters and remains the same regardless of glass temperature changes during the tapering process. Warm Taper Image (WTI) provides real time control based on the fiber brightness (temperature) during tapering.

It is well known that if glass material is heated to a certain temperature, it will emit visible light with the intensity proportional to its temperature. The emitted light can be captured by the cameras and analyzed with the image processing system. The value of the brightness can be then used to control the heating power to obtain a steady temperature of the glass. A heated fiber during the tapering process is shown in the following figure.

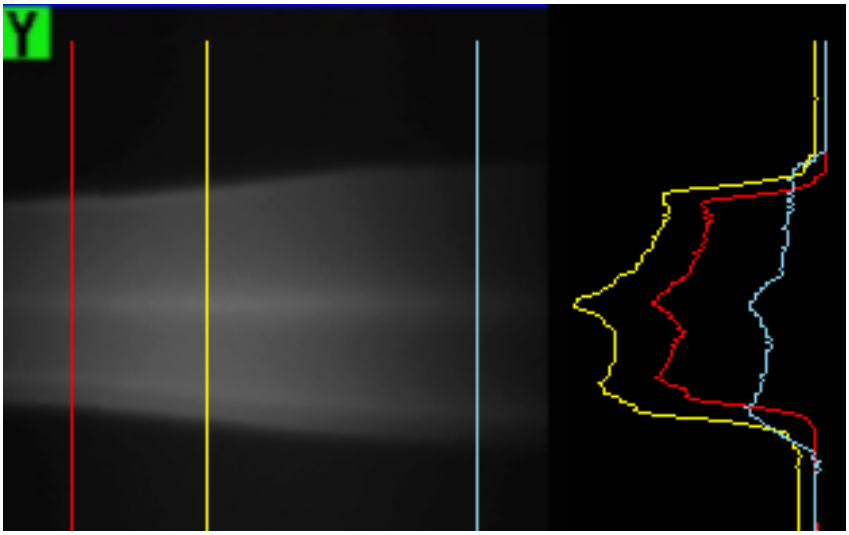


Figure 5.9. Brightness profiles of a heated tapered SMF image. The colored curves are brightness profiles taken at corresponding straight line locations.

From the Figure 5.9, it is obvious that the average brightness on each vertical line is dependent on fiber location and camera shutter exposure setting. For some fiber types, very low temperature has to be used for tapering. The WTI is normally very dark during the process and a brighter ***WTI Exposure*** setting should be used to see an image. On

the other hand, too high a ***WTI Exposure*** will cause image saturation and thus loose the ability to be used for temperature control. To manually change exposure of the machine, you may drag the slide-bar to the desired value, and then click one of the side arrows of the bar when ***WTI OFF*** is not selected. An appropriate exposure setting needs to be determined for a specific fiber type. The WTI controls provides those adjustments.

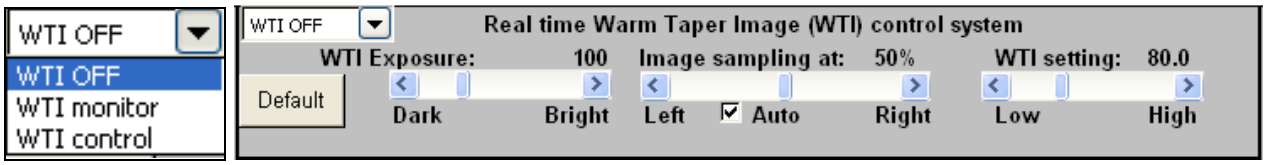


Figure 5.10. Setting for warm taper image monitoring and temperature control

When ***WTI monitor*** is selected in the drop-down box on the left, the current brightness value will be shown as ***WTI setting*** value on the right. The current brightness value is measured at the location of ***Image sampling*** point with current WTI Exposure setting. If ***Auto*** is checked under the ***Image sampling*** bar, the brightest location will be automatically searched, the brightest position is shown as ***Image sampling*** value in percentage of the screen with the most left as 0% and most right as 100%. During the tapering process, by monitoring the ***WTI setting*** value (as current brightness) carefully as well as the live video displays on the machine monitors, an appropriate WTI target value can be determined for the temperature control.

By selecting ***WTI control*** in the drop-down box and inputting the appropriate WTI target value (by dragging the ***WTI setting*** bar), the process is ready for the real time temperature control for the next taper. When the ***WTI control*** is selected, the ***Waist Add*** does not add power any longer. Instead, it adds extra intensity (plus or minus) to your ***WTI setting*** value for the waist. For the control to work, you also need to remember to switch to full live X view and full live Y view on the two monitors before tapering. However, not all fiber types and taper shapes are good for the WTI control. For example, some fibers or tapers are too dark to see any warm image during a period of tapering process. It is impossible to do the temperature control without seeing the warm image.

In the case WTI is not necessary for tapering process, ***WTI OFF*** should be selected. This selection will allocate more PC capacity for the tapering process control. Since WTI real time control needs to do large amount computations on image processing, it is recommended to turn off unnecessary programs on the PC, such as web browser windows. For some older PCs, it might be a good idea to select ***WTI OFF*** in order to get enough resolution on the main tapering process.

6. Making tapers with PC control

After setting all necessary parameters, an operator can either make a taper from the PC software interface, or use the splicer alone in production line. The steps for making tapers using the PC GUI will be described in this chapter.

6.1. Machine initiation for taper process

Before loading fibers for tapering, the Z-motors should be moved to correct position for the process. Please make sure that the splicer is at ***READY*** state and then click the ***Initiate*** button on the PC screen. If you change or edit the splice mode after the initiation, you must re-initiate again since the motors may be reset to the home position after your splice mode changing or editing.

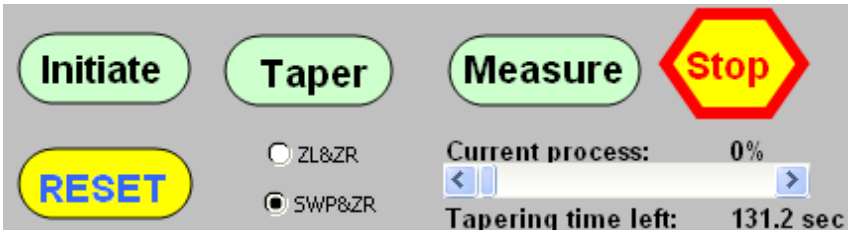


Figure 6.1. Operation panel for making a taper with PC control.

During initiation, the machine will recheck the logic of the design parameters and then move the motors to the desired position. While motors are running, the control buttons are grayed out but the motor indicators are green until the corresponding processes are completed.

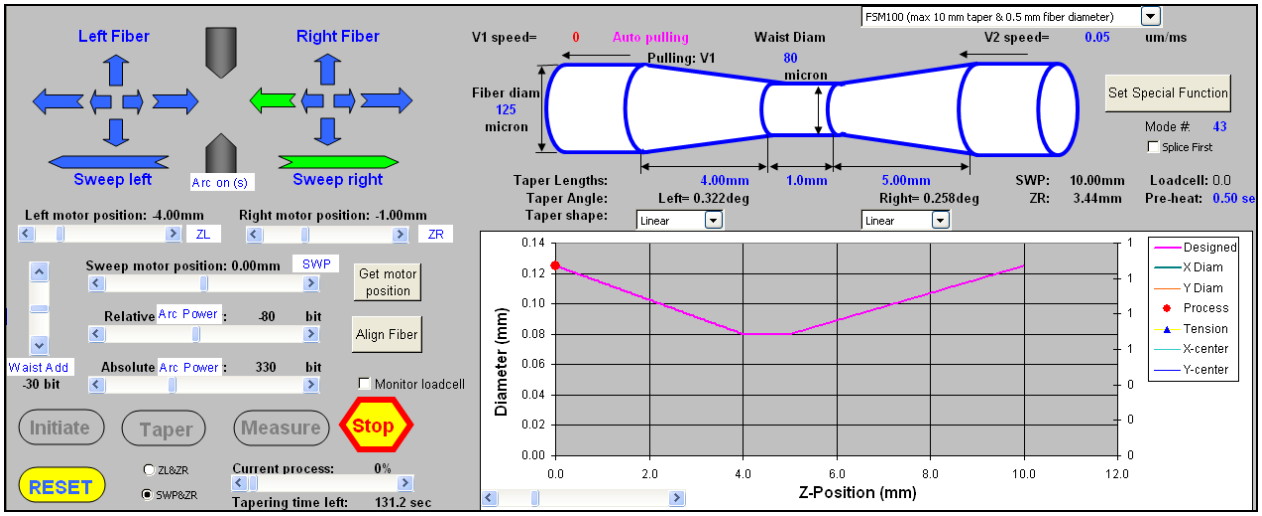


Figure 6.2. ZR and Sweep motor is running during initiation.

During the initiation, if you want to stop the operation immediately, you can click the ***STOP*** button at anytime. You can also reset the machine by clicking the ***RESET*** button. The ***STOP*** button stops motors at their current position. The ***RESET*** button will send the motors to their home position.

6.2. Splicing before tapering

After the initiation process, the fiber holders may be far away from the center compared to ordinary splicing. If you are going to splice fibers before tapering, you need to manually adjust the fiber in the fiber holder to position the fiber end as close to the screen edge as possible. It is best if you can see the cleaved fiber ends on the edge of screen as shown below in Figure 6.3. If you do not pay attention to the initial fiber starting position, the fiber and V-groove may be automatically moved forward to a ***GAP*** position that is too close to the heating area at the center of the screen. This may either cause a lack of space for motors to travel, or in some cases this may even burn the fiber clamps since one of the V-grooves and fiber clamps may be moved into the heating area.

Important notes for fiber loading: Please pay close attention to the fiber end position after loading fibers for splicing, since the machine does not know your actual strip length. If the clamps are burned, please contact AFL/Fujikura to purchase replacement parts.

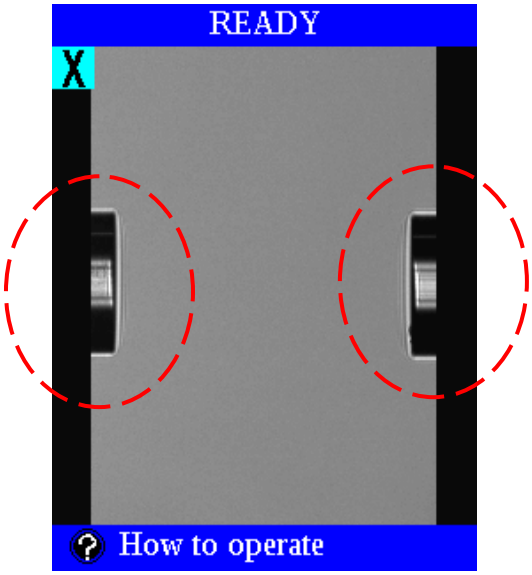


Figure 6.3. Best fiber loading position for splicing before tapering. The red dashed-line circles indicate the critical location for taper processing.

Any splicing mode can be used for tapering. But it is best to optimize the splice parameters for your fiber combination. The correct procedure is

1. Click ***Initiate*** button to set splicer to correct starting position.
2. Load the fibers with the fiber end location shown in Figure 6.3.
3. Press the ***SET*** button on the splicer to complete the splice.
4. When ***FINISH*** shown on top of monitors click the ***Taper*** button on PC.
5. After tapering process is completed, click ***Measure*** button on PC for taper geometry profile measurement (for details see Chapter 8).

Important notes for zoom position: Please make sure that machine is at zoom-out position for LZM-100 machine, otherwise the taper process cannot be started.

6.3. Making taper without splicing

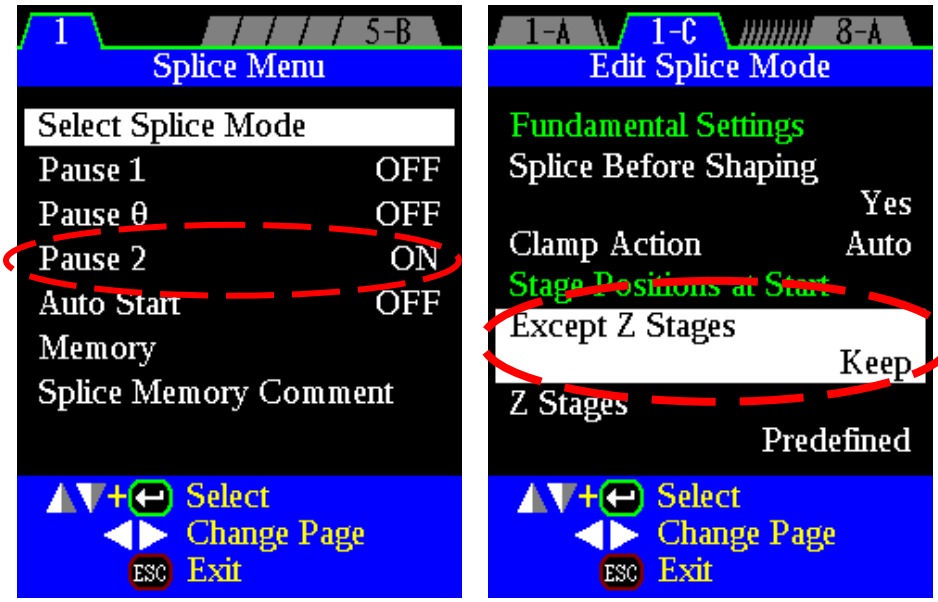


Figure 6.4. Mode settings for V-groove alignment for tapering without splicing.

To taper without splicing, the correct splicing mode needs to be selected with correct fiber diameter information for the v-groove alignment. ***Pause 2*** should set ***ON***, and motor position should be set to ***KEEP*** after the alignment (except Z stages). Before tapering window stripped fiber or capillary, the splicer needs to be aligned with two cleaved fibers. The fiber should have the same diameter as the fiber to be tapered and should be loaded to splicer as shown in Figure 6.3 after the Initiation process. The correct procedure for v-groove alignment is described below:

1. Click the ***Initiate*** button to set splicer to correct starting position.
2. Load the fiber ends to the location shown in Figure 6.3
3. Press the ***SET*** button on the splicer to complete the fiber alignment.
4. When ***Pause*** shown on the monitors, remove the fibers and load the window stripped fiber
5. Click the ***Taper*** button on PC to start tapering
6. After tapering process is completed, click the ***Measure*** button on PC for taper geometry profile measurement (for details see Chapter 8)

Important notes for zoom position: Please make sure that machine is at zoom-out position for LZM-100 machine, otherwise the taper process cannot be started

After one alignment, many taper processes can be made without re-aligning v-grooves. Thus, steps 2 and 3 can be skipped. For loading one piece of fiber to splicer in step 4, it is recommended that to gently pull the fiber with a little tension before closing the fiber

holder clamp. This tension is important to keep the fiber straight during the tapering. A small amount of tension can also be established by clicking the left arrow on the Left Motor sliding-bar, until you see the motor moving by green color. The tension applying technique is illustrated in Figure 6.5.

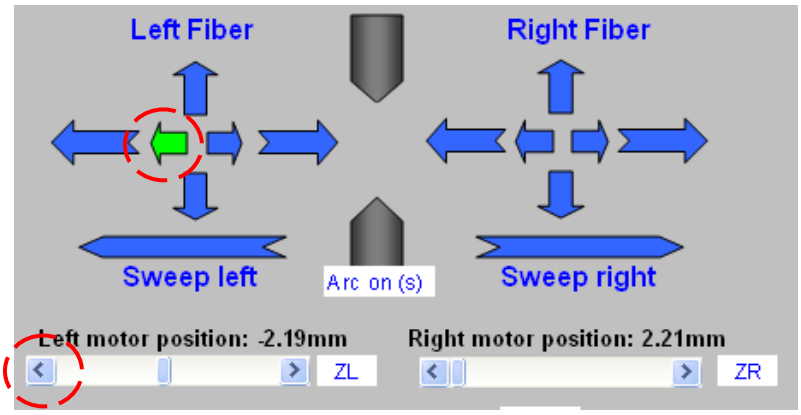


Figure 6.5. Applying a little tension to fiber by clicking the left arrow on the *Left Motor* sliding bar until the motor start moving (green color).

The tension applying process is not necessary for the tapering after splicing, since the splicing is the best process for applying right tension to the fiber.

The tapering process can be stopped any time by clicking the ***Stop*** button. This button will stop all the motors at the current position as well as turn off the heating power in the splicer. It also stops the Excel program process. Once the process is stopped, it cannot be resumed. If you would like to start another taper process, you need to click the ***Initiate*** button again.

7. Making tapers with splicer special functions

As discussed in Section 5.2, the tapering parameters can be sent to splicer, and the taper process can be completed by the splicer alone (without connection to a PC). With the current firmware, only the ***Auto Pulling*** mode with linear taper shape can be accepted by splicers. ***Auto Feeding*** and ***Sine*** taper shapes can only be completed with PC control.

7.1. Special functions for adiabatic tapering in splicers

There are 10 steps of operator programmable special functions built into the splicer firmware. It can be programmed for many different types of glass processing work. Performing an adiabatic taper is one of them. To make adiabatic tapers with auto-pulling (constant feeding speed), special formula types are defined. As one example shown in Figure 7.1, we can see how the taper parameters are defined in the splicer and how the parameters are transferred from PC to splicer.

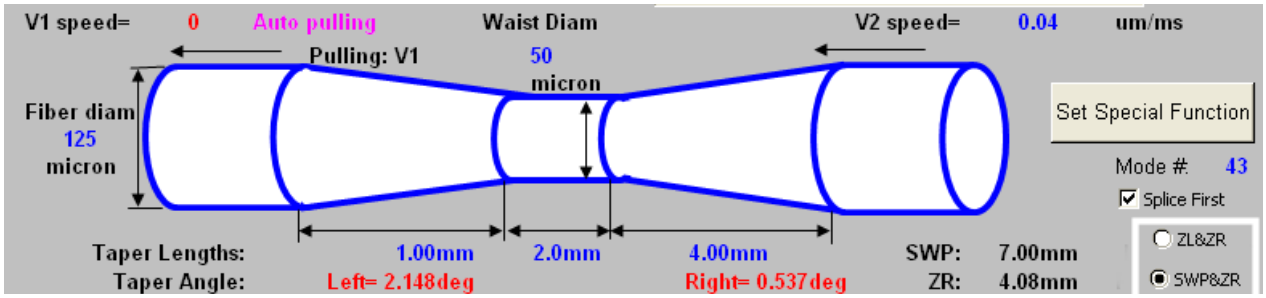


Figure 7.1. One taper example with Sweep and ZR motors, splicing before tapering, and constant feeding speed.

After transferring the tapering parameters to a splicer, the typical parameters are shown in Figure 7.2, 7.3 and 7.4.

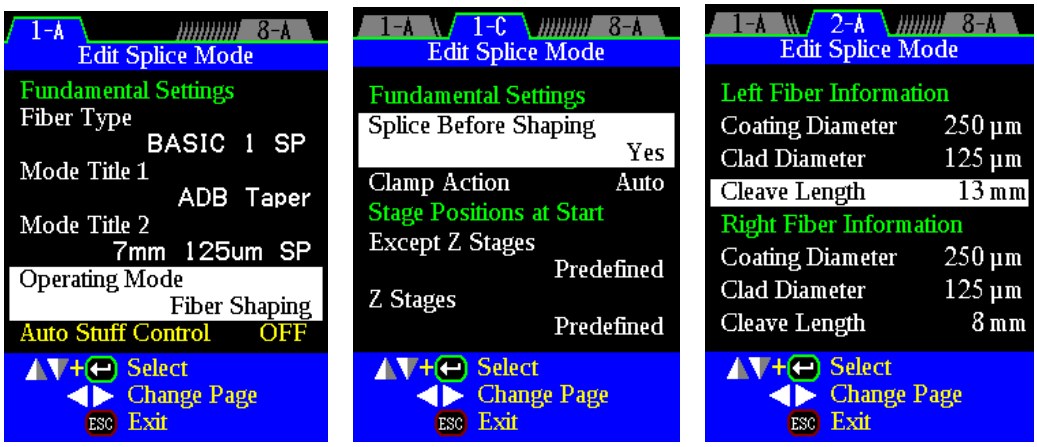


Figure 7.2. Typical splicing parameters for the taper design shown in the Figure 7.1, where fiber shaping mode is used with the selection of splicing before shaping.

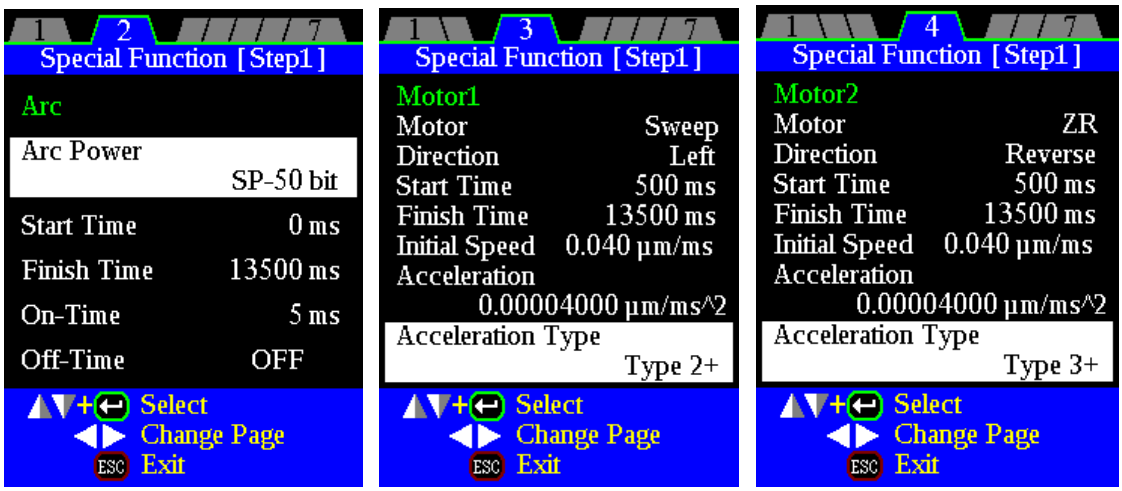


Figure 7.3. Typical *downward* tapering parameters for the taper design shown in the Figure 7.1, where special acceleration types are used for the adiabatic tapering

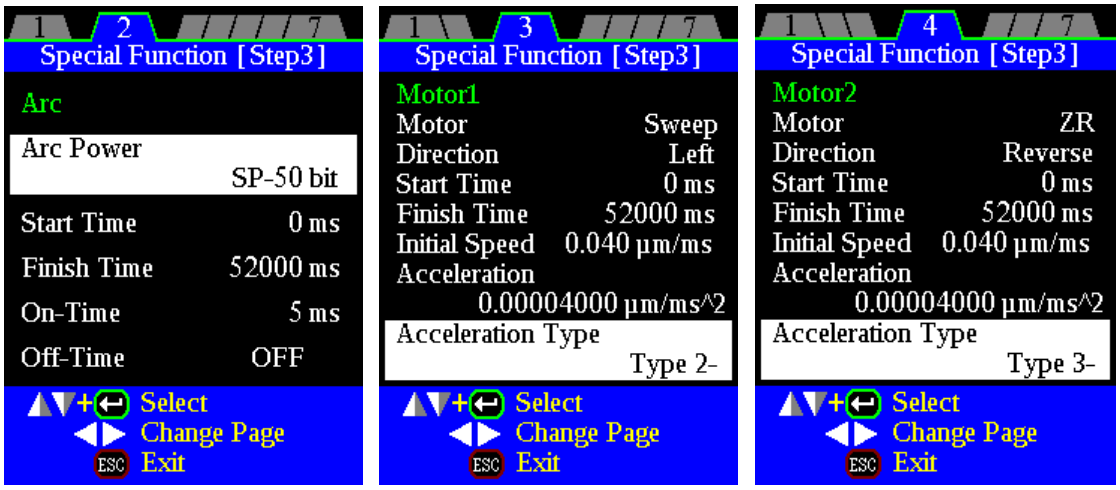


Figure 7.4. Typical *upward* tapering parameters for the taper design shown in Fig. 7.1, where special acceleration types are used for the adiabatic tapering

For the parameter shown in Figure 7.3 and 7.4, the rules are listed below:

- There are 5 possible selections of acceleration types:
  - Taper 1 Constant acceleration (for waist tapering)
  - Taper 2+ (for Sweep motor downward tapering)
  - Taper 2- (for Sweep motor upward tapering)
  - Taper 3+ (for ZR downward tapering with the Sweep motor)
  - Taper 3- (for ZR upward tapering with the Sweep motor)
- With "Constant acceleration", the motor runs in a traditional way as before
- For the rest of parameters setting
  - R = wrist diameter / fiber diameter (inversed taper ratio)
  - L = taper section length
  - Finish time = $L(R^2+R+1)/(3v)$
  - Initial speed v = fiber feeding speed
  - Acceleration = R/10000

7.2. Transferring taper parameter to splicers

As discussed in Section 5.2, when the taper design is verified with PC control and you would like to perform the specific taper with splicer only (no PC connection necessary), you can click the ***Set Special Function*** button to setup your splicer for the taper. Then a few message boxes will show up requesting your decisions.

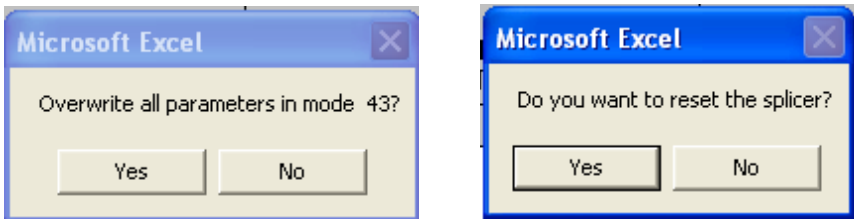


Figure 7.5. Message boxes shown as reminders for you to confirm.

Before clicking ***YES*** buttons to the message boxes, you need to make sure that the parameters in the mode is OK to be overwritten, and that there are no fibers loaded in the splicer since the fiber may be damaged during the ***RESET*** of splicer. If you answer ***YES*** to the ***RESET***, the machine runs reset process to activate your new parameters, goes to your selected mode as current mode, and moves the sweep motor to the correct starting position if SWP&ZR tapering mode is selected. In the case ***NO*** is clicked for ***RESET*** message box, you are required to perform all the above processes manually.

7.3. Making tapers with or without splicing

The tapering process is straight forward with ZL&ZR motors. After loading two cleaved fibers according to the illustration in Figure 6.3 for splicing before tapering; or a window stripped single fiber (with manually applied low tension), the tapering process can be performed by pressing the ***SET*** button on the splicer. For the single fiber tapering, ***SET*** button needs to be pressed once more when the ***Manual Alignment*** window is shown in the monitor, However, for SWP&ZR tapering mode, you have to manually move the Sweep motor to the correct initial position, since the sweep motor is always being sent back to its home position after the tapering by ***Special Function***.

The procedure for making taper with SWP&ZR mode is listed below, where we assume the taper parameters were already sent to splicer and one taper was already completed.

1. Load a stripped and cleaved fiber on left v-groove with strip length 9 mm.
2. Move the Sweep motor manually to right until the fiber end can be seen as illustrated in Fig. 7.6
3. For splicing, load the right fibers with the fiber end location shown in Figure 6.3. Or for tapering with single fiber, load the fiber to on both sides with a little tension.
4. Press the ***SET*** button on the splicer to complete the tapering process.

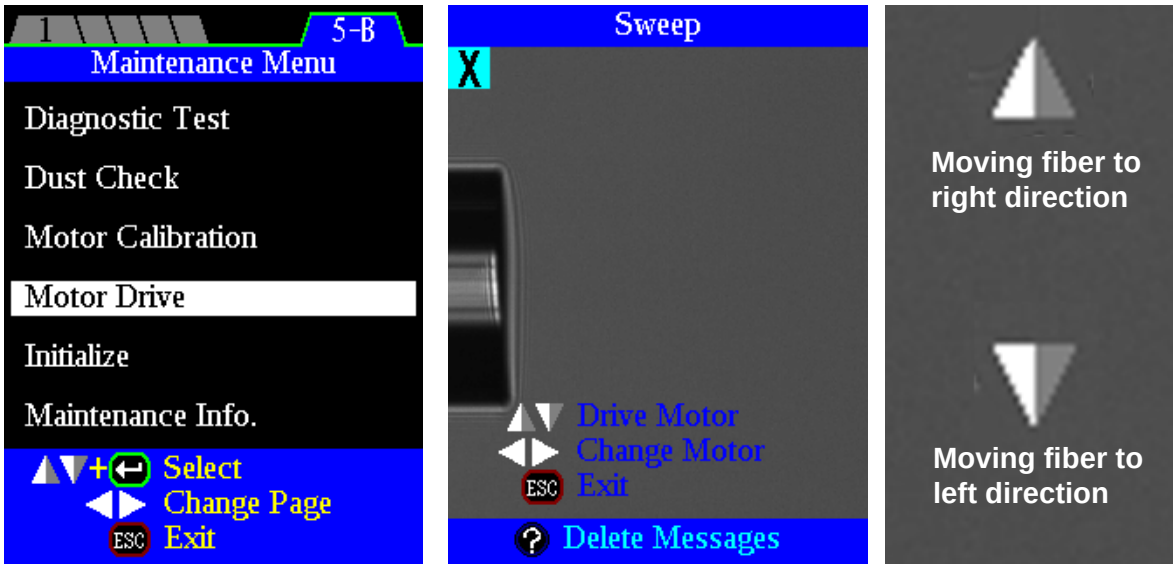


Figure 7.6. Manually set sweep motor initial position for tapering in SWP&ZR without PC connection. The left fiber strip length is 9 mm.

7.4. Limitation of tapering without PC control

With the current firmware, there are some limitations in tapering process when not being controlled by a PC. The limitations are:

1. Cannot make taper with auto feeding speed (i.e. constant pulling)
2. Cannot make taper with sine curve on up and down taper
3. Cannot measure the taper profile
4. Cannot adjust for waist power (constant power used for entire tapering)
5. Cannot monitor or control based on WTI information
6. Not easy to move fiber to initial position if ***SWP&ZR*** mode is used

Thus, the non-PC-controlled tapering process is in general not recommended, except for production lines where a PC may not be allowed or is not available.

8. Measuring taper diameter profile

After the tapering process, no matter how the taper is performed (with PC control or splicer only), you can use PC to make geometry measurement of the taper.

8.1. Making measurement

There are two types of measurement methods. With the ***variable speed*** method, the fiber travels continuously from the right side of taper to left side of taper with the user defined speed from 0.01 to 1.0 mm/sec. The taper diameter is measured at center of the screen during the fiber movement. For obtaining a high resolution measurement, a lower speed should be used. This will increase the measurement time. With the ***Image Stitching*** method, the taper will move from left to right screen by screen. After each movement, an image will be captured and the diameter measured. The background illumination may not be completely uniform across all images taken, so the diameter profile may show a small ripple at edge of each screen from image processing. This ripple is not actually a physical part of the taper. All pictures taken during the process will be stitched together in the ***Image*** page for point to point measurement.

Figure 8.1. Measurement method selection at right side of control panel.

For a taper with a thin waist, it is recommended that the taper be slightly tensioned before measuring, since a loose fiber may cause some degree of vibration during the fiber movement. The vibration may reduce the measurement accuracy or add false ripples to the measurement profile. The method for fiber tensioning is discussed in Figure 6.5.

The ***Sweep motor*** is used for measurement process on FSM-100 machines. For LZM-100 the ZL and ZR are locked and move simultaneously. The ***Sweep motor position*** bar will show you the motor position before and after measurement for both FSM-100 and LZM-100. For measuring the taper more than one time, the initial value of ***Sweep motor position*** after the taper should be noted and reset to that value before attempting a repeat of the measurement.

Figure 8.2. Question box if the measurement process is not started at taper end.

For most of cases, the measurement is started at the end of taper process. When the ***Measure*** button is clicked, the measurement process starts right at the end position of the taper. However, for the cases if the taper needs to be measured 2nd time, or re-measured after stopped, the current position may not be at the end of taper. A question box may show up to make sure if you want to move to the taper ending position. If ***No*** is clicked, the measurement will start from the current position. In this case you need to manually stop the measurement at your desired point, since the measurement process will always trying to complete the entire length of designed taper regardless where the starting point is.

The measurement process can be stopped at any time by click the STOP button.

8.2. Measurement curves

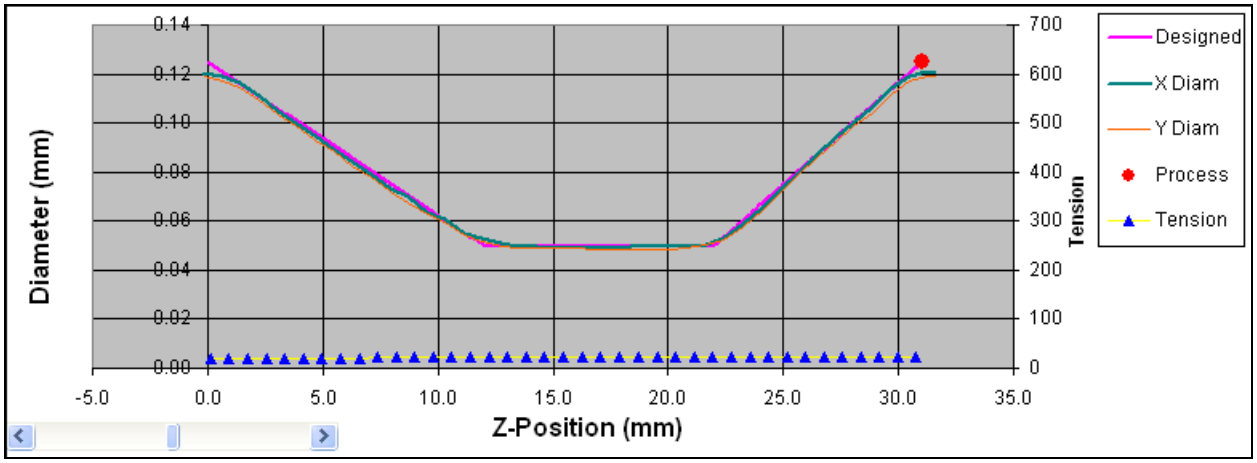


Figure 8.3. Typical measurement chart with design curve (pink), X/Y diameter measurement curves (green/yellow), and tension curve (for LZM-100 only).

The measurement curves are plotted on the same chart as the design curve. Since the measurement starting point may differ slightly each time, the measured curve may not align with designed curve horizontally. By using the sliding bar on the left bottom of the chart, the measured curves can be shifted horizontally to achieve a better compare between designed and measured curves.

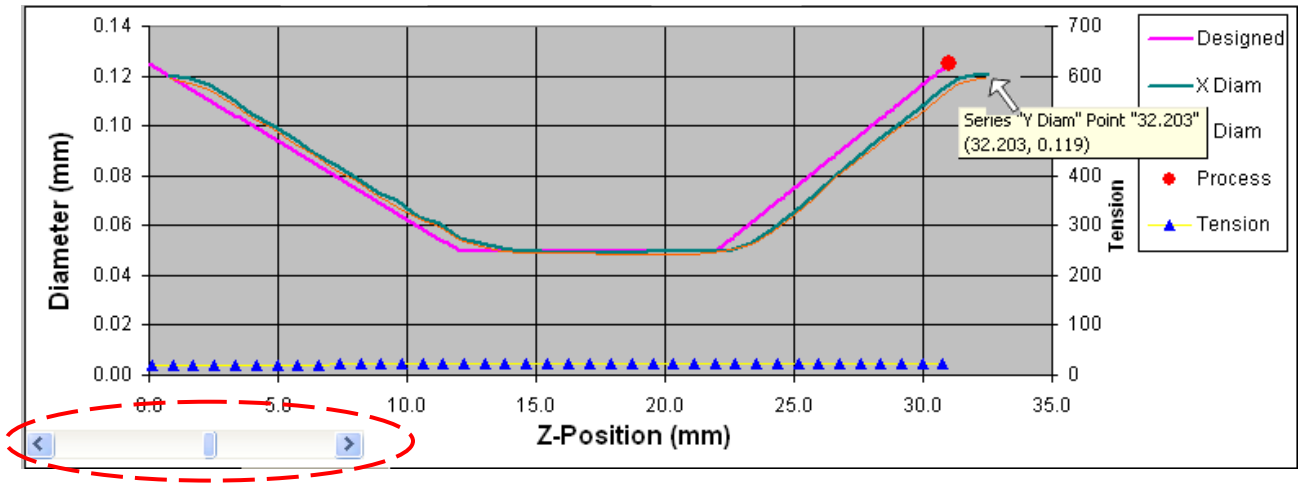


Figure 8.4. With the sliding bar on the bottom, the measured curves can be shifted left or right in order to make a better comparison to the designed curve. Moving the cursor on the curve, the X and Y values can be read at any position.

8.3. Taper images

After the taper measurement is completed, the taper images can be viewed and measured.

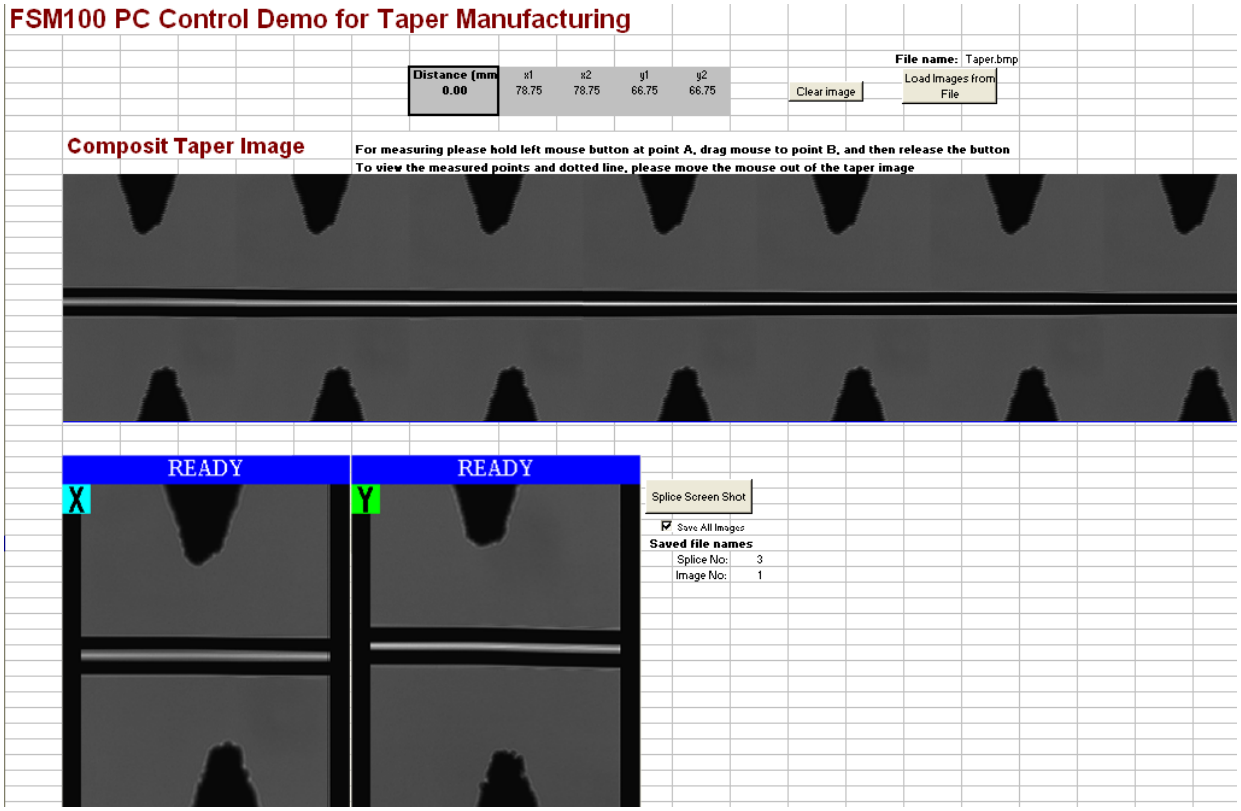


Figure 8.5. Example of the *Image Page.* The electrodes can be seen for FSM-100, but not in LZM-100

In the middle of the ***Image Page***, there is a ***Composite Taper Image***. The images taken during the measurement process will be stitched together automatically to show you a complete overview. The image in this area is user measurable. After selection of the image, you can see a thin cross when you move your mouse across the stitched images. By holding down the left mouse button at the point 1 and dragging the mouse to the point 2 then releasing the mouse button, you can read the distance between point 1 and point 2 from the display box on the top of the image. Depending on the image resolution, the measurement accuracy may not be as good as the data shown in the ***Control Page***. When the mouse leaves the image area, a yellow dotted line will connect point 1 and 2 to trace your measurement path.

Figure 8.6. Trace of measurement (yellow dotted line on the left to measure fiber diameter) and distance between points 1 and 2 on the top of the image

Important note for measuring in magnified Windows: With Excel, you may magnify the entire page and then make measurement. For Office 2003, this magnification should not be larger than 190%. Otherwise you may see a black image. **For latest Office 2013, you should not use any magnification. If you do, the entire screen will be black immediately after you select the image. If this happens, move the mouse to the bottom of screen with no clicking.**

8.4 Image file save and load

If the ***Save All Image*** box is checked, all images taken during the measurement process will be saved with serialized image numbers. However, no image will be taken if the ***Variable Speed (no images)*** is selected in the control page as the ***Measurement method***. The images will be saved in the same folder as the current Excel program location. The splice number and the image number will be incremented starting from the current number. You can edit the starting numbers as you wish.

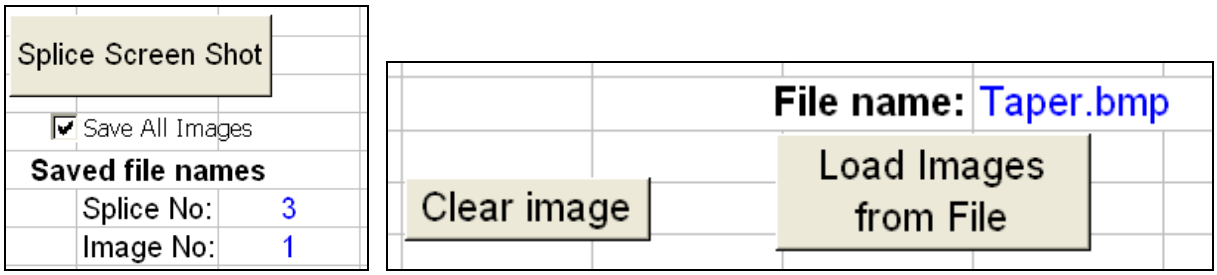


Figure 8.7. Controls for image file save, load, and clear

By clicking the ***Splicer Screen Shot*** button, the current images on the splicer monitors will be taken and saved to the current folder with the current splice and image numbers.

Immediately after the taper is measured, the stitched image for distance measurement will also be saved with a constant file name "Taper.bmp". If you want to keep this file for future use, you must rename it. Otherwise, this file will be overwritten at the next taper measurement. If you want to reload any of your renamed image files, you can input your file name and then click the ***Load Image from File*** for additional distance measurement activities and analysis.

All the images displayed in the ***Image page*** will be removed by clicking ***Clear image*** button. This is not necessary for the tapering and measurement processes. But if you would like to save this Excel file, the file size can be significantly reduced by clearing the images.

9. Manual control of motors and arc (lase)

Easy control of motor positions and heating of the fiber at a desired time are useful features for manually positioning and shaping the fiber. This PC program provides many options for manual motor control and heat control.

9.1 Motor manipulation

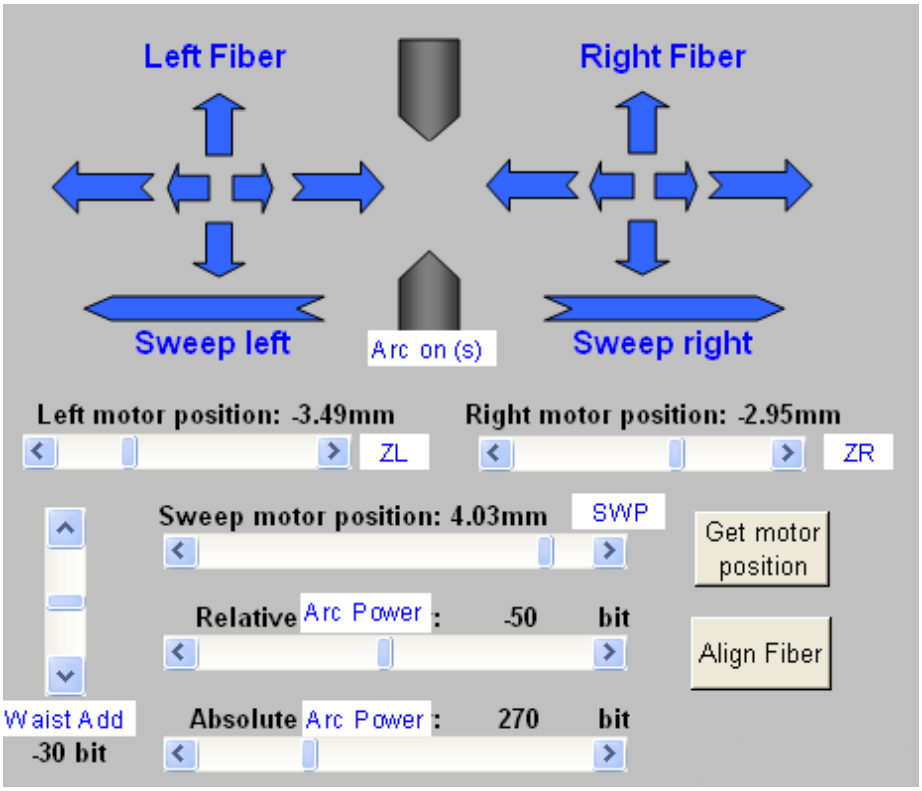
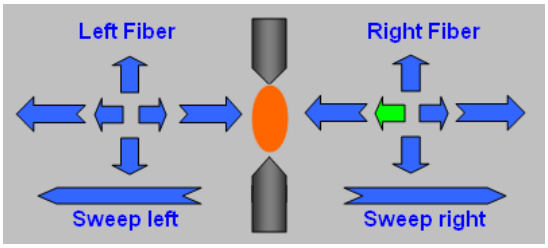
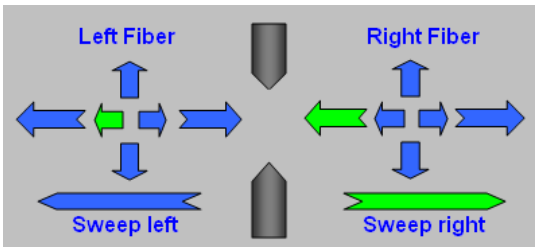


Figure 9.1. Controls for motors and heat (arc discharge or CO_2 lase)

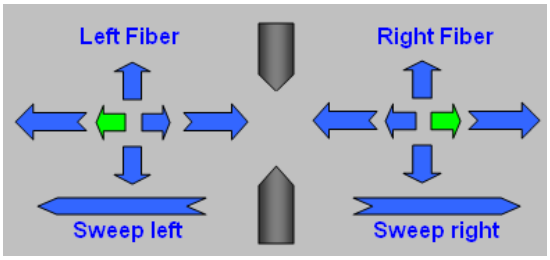
The blue arrows in the control page control the motor position. When you click one of them, the corresponding motor will move and that arrow turns green. To stop the motor movement, click the green arrow again and it will turn back to blue when the motor stops. If the black electrodes and the area between the electrodes are clicked, the arc (for FSM-100) or the CO_2 lasing (for LZM-100) will be initiated. You can stop the discharge (or lase) by clicking it again. Several motors and the arc (or lase) can be running at the same time. If you would like to stop all motors and the heating at the same time, you can click the red ***STOP*** button. If you want to move the ***ZL***, ***ZR***, or ***SWP*** motor by a certain distance (in mm), you can simply type in a positive or negative number to the corresponding label and then type ***Enter*** key on your ***PC***, the motor will move immediately. You can also drag the slider bars to move the motors. If a time value (in sec) is typed into the ***Arc on*** label box followed by ***Enter*** key, the arc (or laser) will be on for that amount of time with the power at the sum of ***Absolute*** and ***Relative Power***. Similar to motor control label boxes, all the power control label boxes can also have a value typed in rather than dragging the slider bars.



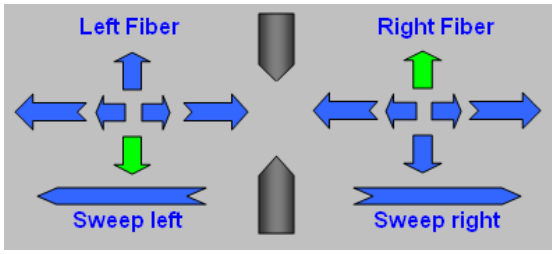
(a) Feeding right fiber to heat



(b) ZL slowly, ZR quickly, and sweep



(c) Slowly pull fiber apart



(d) Left fiber goes up and right down

Figure 9.2. Examples of different motor moving control

As said before, the motor position indicator bars can also be used to move the corresponding motors by dragging the scroll or click and holding the arrows on the sides of the bars. The indicator bars can also show you the current motor location after clicking the ***Get motor position*** button. If you have moved the left and right fibers to the center of screen with a gap, by clicking ***Align fiber*** button the fiber will be aligned using the X/Y alignment method specified in the current splice mode.

9.2 Motor moving range

Depending on the machine type you are using, the motor movement range is different. The following table shows the available ranges of the FSM-100 and LZM-100 splicer families.

Machine	ZL	ZR	Sweep	Heat Power	Rotator speed
FSM-100	5 mm	5 mm	+/- 5 mm	180 – 500 bit	50 deg/sec
FSM-100+	18 mm	18 mm	+/- 18 mm	180 – 800 bit	50 deg/sec
LZM-100	150 mm	150 mm	+/- 150 mm	1 – 1000 bit	150 deg/sec

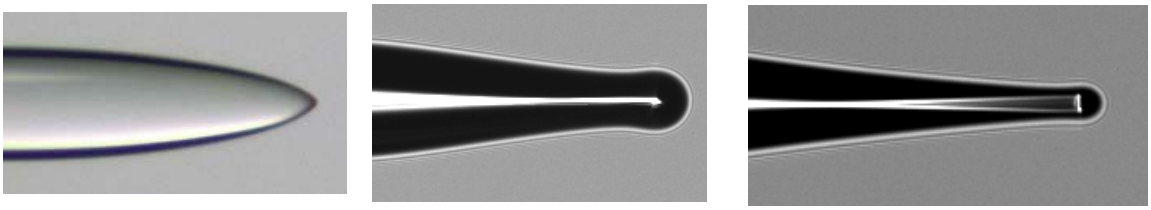
Table 9.1. Available range of different machine types

If a motor reaches its moving limit, it will stop even if the arrow on the screen is still green. On certain occasions the yellow warning message "***Motor overrun***" will blink on the splicer display.

Due to the motor range limitations, if you want to make a taper exceeding the capacity of the machine type, you will also see a warning during your taper design. For example, if you would like to make a taper of 11 mm long with using FSM-100P, you will see the blue/black number become red, since it exceeds the ZR range of 5 mm of FSM-100P.

9.3 Examples of manually made tapers

Some short tapers made with manual control are shown below. In the examples, we can see the taper can be made into different shapes.



Axicon taper **Taper with lens** **Probe**

Figure 9.3. Examples of various tapers made with manual glass shaping.

The manual operation is more of a development process method rather than a production method. Although you can create many different taper shapes, it may be difficult to repeat and achieve consistency. AFL may be able to help develop enhanced software or process development and optimization to create a more consistent desired taper with PC control for these special applications.

10. Summary

AFL's Taper software is continuously being reviewed and improved. If you have any suggestions or comments, please contact the AFL OEM sales team or the splicer engineering team.

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