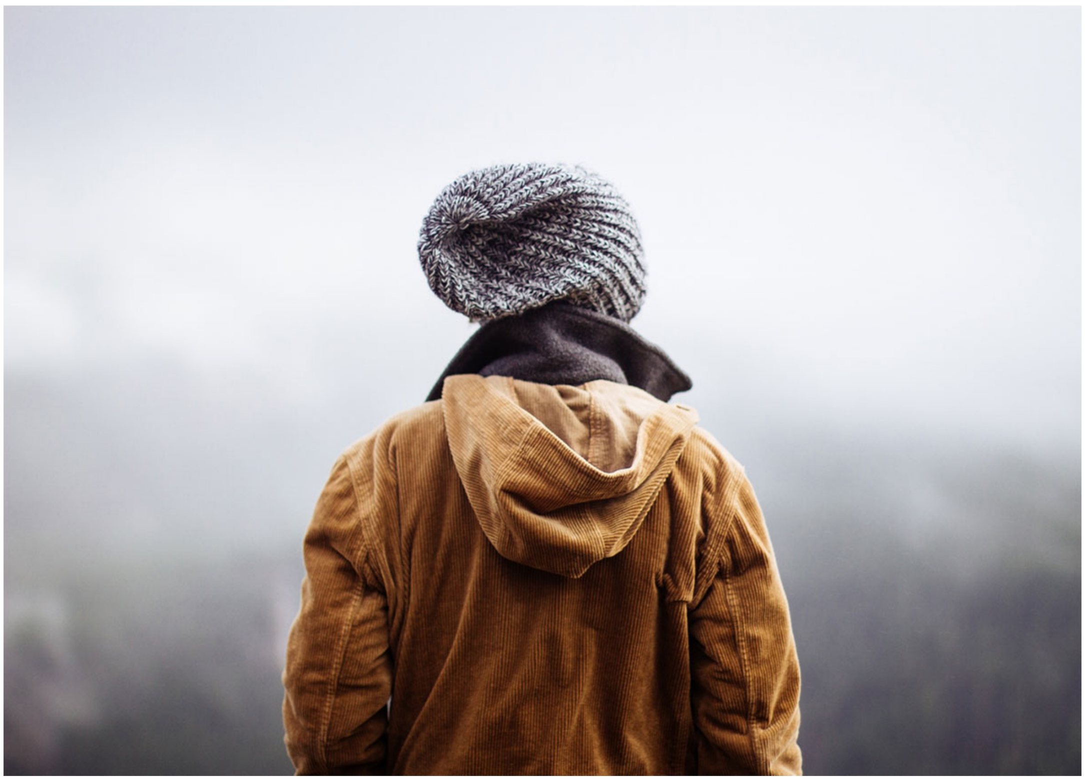
Prusa MMU2/S Accessory for Prusa i3 Mk3S+

Multi Material Unit V2/S

Operation, Bugs, Tuning and Proposed Enhancements



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About this report

This report is an attempt to address the subject matter in an objective, open and positive or neutral way. Information is provided about the way in which the MMU/2 operates, along with contextual information about necessary adjustments and tuning. Recommendations for product improvement are provided.

The information is presented in a different style than found in Prusa Knowledgebase articles.

Along the way, various common issues are canvassed. These are further discussed at the end of the report, with positive suggestions for improvements.

This is the second version of this report, created on 2022-10-09.

This Document

- Is written solely by the author, Bryn Parrott. The contents of the document represents the view and opinions of the author although other people may hold similar views. The basis of any statements made herein is based upon the experience of the author along with results of online publicly available research and opinions and advice offered by other people. Some such people are acknowledged within the report and others are not.

The author may, when requested, offer some evidence to support claims made; but such evidence (apart from the author's own experience) is not included in the report for the sake of brevity and clarity. It should be noted that much of such evidence is already held by Prusa as part of customer interaction records of online Chat systems and Prusa's own email system.

The report is truthful to the best of the author's knowledge and experience, and it is NOT intended to harm the reputation of any party.

Effort has been expended by the author to make the writing style neutral, unbiased and objective so far as humanly possible in context of the subject. Any implied criticism (of Prusa or any other party) should be taken in context of making a positive contribution to the MMU product, enhancing its utility for users and ultimately the betterment of Prusa's reputation.

Whilst the link that provides access to this report online is publicly accessible via Google Drive attribute, in fact that link is not published in any media with the exception of private email messages. The author provides such links to specific recipients on a highly selective basis, not by public broadcast on any medium.

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Revisions

Revision Number	Date	Description
0.1	**2022-09-19**	**Initial**
0.2	**2022-10-09**	**Added** 1. **Octopi idea for better diagnostics P25** 2. **Analysis of Voltage issue on MMU MM-Control P11 and P28**

The bottom line

The final topic in the report offers a range of suggestions for improvement of the MMU2/S product. The author acknowledges that Prusa is under no obligation to effect such enhancements or corrections to the product. Such a decision is entirely within the purview of Prusa.

However the intent of the author is to canvas an overview of user experience with the product, while it is acknowledged that not all users share the same experience (or at least, publicly deny such experience, such denials being truthful or untruthful).

The overview is an attempt to illustrate how such experience may detract from user perceptions as to the utility of the product. The author has the fervent hope that this will persuade Prusa to consider continued support for the MMU product (in the light of future product developments including the XL printer model) and offer further improvements.

Introduction

What is the MMU2/S ?

The Prusa MMU2/S is an accessory for Prusa i3 Mk3S/+ 3D Printer designed to enhance the printer, allowing it to use up to 5 filaments in the same model. Typically this is used to print models in multiple colors.

This accessory is unique among 3D printer manufacturers. Having the MMU available in the product lineup helps Prusa to sell printers, with some customers choosing the Prusa MK3S+printer *BECAUSE* it has MMU available.

User Experience

Whilst many people say online they have a good experience using the MMU, others say they do not. In the experience of the author, it can prove difficult to get the best use out of the accessory. It takes some considerable time to tune MMU operation for best reliability and print quality.

The proportions of happy customers to unhappy customers is the stuff of opinion: myth and legend, since there have been no actual published survey results. The only way to establish the truth concerning the level of customer satisfaction with the MMU2/S is to conduct an unbiased survey of users and to publish the results.

The difficulties arise through:

- Poor understanding of how the accessory works
- Poor understanding of underlying engineering principles (such as fluid flow dynamics)
- how to make the best tuning adjustments to the device
- slicer parameters
- how best to correct issues that become evident.

The poor understanding arises from incomplete documentation and from a lack of consistency among advice tendered from different sources of support. There is difficulty assessing the veracity among the sources of support. Prusa support often provides conflicting instructions depending on whom you speak to. Prusa support appears to be trained to ignore user suggestions and negative feedback about the accessory.

The Author's experience with MMU2/s

1. The author purchased MMU2/S along with his first Prusa Mk3S+ in March-April 2022 time frame. The printer was factory-assembled. The MMU was installed on the printer a few weeks after the printer was delivered. The author spent some time working with the printer in standard operation before installing the MMU2/S. This was a very positive experience.
2. The author initially used the printer with MMU fitted running single filament prints. This included use of a range of material: PLA, PETG and TPU. TPU proved to be problematic, but prusa support provided some guidance to using this material on a single filament basis. Single mode printing with MMU was however relatively problem free.
3. Subsequently issues began to develop when multi material printing was attempted. The author sought advice on Facebook groups and via Prusa Support (@Douglas). Initially, setup and calibration issues were identified and corrected. However it appeared there were issues with the Finda sensor. Whilst ultimately these issues were pinned down to wiring, the Finda probe was replaced by Prusa and a kit of parts was purchased by the author.
4. Later, issues continued with fat filament ends, and prusa support (@Blas) advised the author to replace the hotend. This was because the nozzle temperature sensor was suspected to be off-specification and causing the nozzle temp to be inaccurate, and this was suspected to be causing incorrect filament-end formation.
5. The next problem to be identified was intermittent erratic operation of the idler. This problem had started when the finda probe was replaced and slowly became worse. It rose to the front of priorities after fat-filament ends and extruder jamming was addressed by replacement of the hot-end.
6. Prusa support (@guiliano) advised replacement of the idler. The author printed new idler parts and installed them. However after the new parts were installed, no fault was found upon close examination of the idler, and the erratic operation of the idler continued.
7. The author proffered the diagnosis that the root cause of the issue was an electronic type problem (based on extensive experience and training with electromechanical devices and electronics) because the symptoms were affected when the wiring loom was manually moved. But this diagnosis was resisted by Prusa support, who advised that such a scenario was very rare.
8. However the author then sought another view via Facebook, and user: (@Jan Wieck) proffered the suggestion that Deoxit contact cleaner might be useful. The author purchased Deoxit D and Deoxit G products online. The author applied them to the electrical contacts within stepper motor connectors attaching to the MMU MCU Board.

9. Subsequent testing using benchmark models yielded the result that the issue of intermittent erratic operation had been addressed. The author takes the view that Deoxit likely represents a temporary cure of the problem rather than a permanent fix. It is however a **pragmatic solution** that can be quickly and cheaply applied by users. The root cause really needs to be addressed properly. **That root cause issue is vibration of the MMU wiring loom leading to micro scale movement of the female pins against the male pins.**
10. The author conducted some research via Molex website about the female pins on the stepper motor connectors. It was found there are 3 types of pin. Those having Tin Plate, Thin Gold Plate or Thicker Gold Plate. The type fitted to stepper motors on the MMU were found to be of the tin plated type. The type of male pins on the MCU Board are of gold plated type. The autor formed the view that the differing metal plating may be contributing to intermittent connection noise and failure. Subsequent research yield further information that the tin and gold plated pins have differing operation-related performance, with gold plated contacts having a longer lifetime. And further information supplied by another facebook user indicated that vibration of contacts may cause noise and intermittent contact failure.
11. So the author's considered view, based on this research, is that this may be the **root cause** of intermittent idler operation in his case, and potentially many other cases. And this may also be related to misoperation of Finda probe and failure of the idler shaft parts. Pathways to mitigation of this issue are canvassed in the final section of this report.
12. Further testing of the author's MMU using benchmark files indicates that most issues have now been fully addressed, with the exception of filament end-strings. Certain filaments, namely those from eSun PLA+ appear to be resistant to slicer parameters that are designed to obviate such filament-string-ends. Other filaments, from Prusament, Fillamentum and Botfeeder do respond to the slicer control measures, but not the eSun.
13. Dialog with the filament supplier and reseller is ongoing, with a view to having these filaments replaced. It is too early to tell if these negotiations will succeed or not.

The Author's overall view is that the MMU has presented significant usability issues (Really, it has been a nightmare experience), but some in the user community deny these issues are commonplace, while the author has observed other people describing the exact same set of issues. It is difficult for uninitiated users to distinguish truth from fiction when there is no yardstick or a means to assess the scale of a problem.

As mentioned earlier, it is time that some light was shed on the overall question of MMU reliability and usability. A survey of user satisfaction should be conducted, which may inform Prusa's decision to implement fixes for the most significant issues of concern to most people.

Product Support

Pluses

Prusa provides a superb level of customer support that is available globally in multiple languages on a 24/7 basis. Support operatives are generally courteous and knowledgeable. Support can be engaged via multiple channels: Email, Online Chat, and Prusa-hosted forums. In addition, Prusa provides a knowledge base of documented assembly guides and information on correction of specific issues.

Observation from experience:

- Prusa Support advice tends to favor Root Cause corrections rather than perceived or symptomatic corrections.
- Prusa Support tends to discount textual analysis and observations made by users, no matter how credible, and require visual evidence to support claims made by users.
- Prusa support often demands an extraordinary level of visual evidence to support a user's observations; ignoring the fact it's often difficult for a user to recreate a fault that may occur when they are not watching.

There exist a number of Facebook Groups where users can engage with others about issues they have encountered. There appears to be no direct involvement with Prusa representatives. Knowledgeable users provide advice on ways to address issues encountered.

Observation from experience:

- Facebook users often promote Symptomatic corrections over root cause corrections. This may be viewed as pragmatism in action (I guess).
- It is often difficult to distinguish credible advice based on long experience from Facebook users, and advice based on incomplete analysis.

Minuses

Information is often slow to propagate through the prusa support hierarchy. Prusa Support are NOT based in Prague, but elsewhere in Europe. Prusa support does not acknowledge many of the issues reported by users when using the MMU/2 that are nonetheless real. They will generally only provide support on basic settings. Prusa support does not acknowledge or endorse any of the available 3rd party solutions, leaving unschooled users in limbo.

Facebook Groups provide an eclectic mix of good, well meaning but often incomplete advice mixed with other troll type responses. But it appears that nonetheless, many users go to Facebook for solutions, eschewing Prusa support or Prusa forums. Why is that the case ? This unknown factor should be tested via the aforementioned proposed user survey.

User Skill levels

The MK3S/+ is a popular printer attracting support from a wide range of consumers who may have a wide range of skill levels. Prusa support staff do well to field enquiries from such a wide range of consumers. It has been observed that Prusa provides coverage of support by having staff from all parts of the organization field consumer enquiries, not limited to specialist support operatives.

Consumers are attracted to the multi-color printing facility offered by the MMU/2 but may lack the experience and understanding needed to diagnose and correct issues unaided.

Contributing factors

Poor technical skills and understanding have also led people to apply fixes for perceived or symptomatic rather than root causes of issues. This muddies the waters surrounding the MMU with many fixes for a few issues flying around, each with vehement adherents. Prusa fails to provide any guidance or endorsement of any user-developed solutions or acknowledgement of the issues they try to correct. Users that encounter issues are forced to conduct their own evaluation and lacking appropriate skills or knowledge may needlessly waste their effort and resources. There needs to be a way to weed out ‘solutions’ that are ineffective or do not correctly address the issues.

Furthermore there are aspects of the product design that could stand some improvement, but there has to date been no sign that Prusa has any intention to make needed improvements.

Impact of Prusa XL Model

Prusa have released details of an alternate product (to be available in 2023) , the Prusa XL printer, which (can have) multi material capability optionally built in, using a completely different design paradigm.

So, the indications are that Prusa have perhaps moved on and may no longer support further improvements to this MMU design. Certainly development of the XL model may drain resources that might otherwise work on improvements to the MMU.

But the XL model of printer is expensive and so it seems likely sales of the MK3S+ printer will continue, and with it, demand for the MMU accessory. Thus the MMU will likely continue to have a place in the Prusa product lineup. So I suggest it is reasonable to expect that there is a strong case for ongoing product improvement.

But what is the truth ? Only Josef Prusa knows the answer and he has not saying anything publicly about the future of MMU/S to date.

MMU MCU Voltage Supply

The MMU MCU (MM Control) board directly controls operation of the MMU. THE MCU is ATmega32u4, operating nominally at 5 volts.

The MCU operates as a slave or satellite processor under control of the Einsy main MCU for the printer. Control is effected by serial communication. The serial communication appears to be regular asynchronous single unbalanced configuration. The communication speed is not recorded, and can be set in firmware by UART parameters.

Comment: The MCU board has 3 x stepper motor drivers of type TMC2130 (Trinamic) installed. These devices are wired to accept +24 v main supply voltage. The devuce has capability to internally generate 5 Volts for logic operation but this capability is negated by the circuit design. All 3 TMC2130 drivers are connected together via 5v-MOT rail, which is derived from 5 volts supplied from Einsy via a SK310SMA Schottky diode D1 and a LP filter. T**he diode has a forward voltage drop of ~ 0.8 v.**

It is possible to provide 5 volts to the system via USB connection, but this powers only the MCU chip via Vbus directly. Indirectly the Vbus line connects to 5V internal rail via a BAS16HT1 diode, having a forward voltage drop of 1.25 V @ 100 mA current.

- Measurements:
  Voltage supplied from Einsy via P2 connector: 20V (nominal 24 V), so it is lower than specification given on the circuit diagram. However the +24V rail is used only for stepper motor operation, and 20V is within the nominated range for Vs.
- Voltage supplied from the Einsey via P1 connector Pin 1: 5.0 volts.
- Voltage measured at P6 PIN 1: 4.2 V. Nominal 5 Volts, so it seems low, however it's within the range for 5 Volt logic circuits. The difference is entirely explained by the 0.8 volts of forward voltage drop across D1 diode. **The basic premise of the customer observations is verified.**

So, a group of Prusa customers have declared on FB forum and Prusa forum that the 4.2 volt voltage found on the 5 Volts rail is lower than it needs to be, and that this is contributing to some misoperation of the MMU. They provide evidence that the 4.2 V supply is outside the limits for ATMega32u4 operation at 16 MHz, and this may contribute to instability of the MMU. They say that this is a bug in the circuit design. Their correction to this issue is to add a secondary supply by way of USB connection. Its problematic because of the need to delay the application of the secondary supply.

Link to Prusa forum discussion on this issue:
https://forum.prusa3d.com/forum/original-prusa-i3-mmu2s-mmu2-hardware-firmware-and-software-help/i-found-serious-design-error-in-mmu2-electronics-hardware/

The link to the bug report on this issue :
https://github.com/prusa3d/MM-control-2.0/issues/15

MMU Operation.

In standard configuration, the MMU is mounted on top of the printer frame, and up to 5 PTFE tubes feed filament from the filament buffer mounted on top of the printer enclosure. Up to 5 rolls of filament feed into the filament buffer.

The purpose of the filament buffer is to provide a temporary store for filament that is unloaded when a filament change occurs.

In Operation, the user:

1. Inserts the filament to the MMU through the buffer
2. Causes the MMU to load the filament
3. Checks MMU adjustments

Loading filament

The user mounts rolls of filament onto the roll holders. Filament is fed into the filament buffer entry PTFE tubes, and then into the 5 feeding tubes leading to the MMU. This operation requires the user to grasp filament using fingers and push the filament into the small PTFE tube a short distance repeatedly until the filament reaches the MMU entry point, where resistance is felt. .[1]

The MMU idler feed chamber is opened by the user using two screws on the idler cover. Each filament is fed through from the Buffer a further amount and it protrudes from the entry hole into the driving bondtech gear. A further push of the filament allows the user to engage the filament tip with the exit hole, crossing the bondtech drive as it does so. It should then be pushed a further 3-5 mm to fully engage the exit tube. All of this is

[1]This operation is difficult and slow, causing many users to completely discard the standard filament buffer, and instead make an alternative choice. There are several alternatives available to find on the 'printables' model library site. A popular choice is made by "RMU" a British company. Their design is sufficiently popular to be offered commercially in a fully assembled version for a price of GBP 91.00.

necessary because filament tends to have a natural upward curvature and will otherwise not follow the correct path through the MMU.

When all 5 filaments have been threaded through the bondtech drive chamber, the Idler cover is closed, and the two spring loaded screws are inserted and tightened to the correct tension (see next).

The printer can then be powered on.

MMU Idler Adjustment

The amount of tightening of the Idler tension screws is important. Each screw is tightened until the top of the screw is level with the top of the idler frame. And then one turn (360 degrees) more. Both screws must be tightened by the same amount. They can be further tightened if, during initial operation it is found that there is slippage between the bondtech gears and the filament and it is not driving correctly.

After initialisation is complete, loading of each filament into the MMU can be checked using the following procedure:

1. With the filament selector at the leftmost position, press the center black button on the MMU
2. The red led for the first filament will flash and a noise will be heard as filament is fed forward into the selector. The finda sensor is engaged, and the filament is then withdrawn. The Red LED is extinguished and the green LED illuminates.
3. Press the right black button for 2 seconds.
4. The selector moves to the next position.
5. Repeat steps 1 to 4 for each of the 5 filaments.
6. At the end, push the leftmost black button 4 times, each for 2 seconds. The selector will move back to position 1.
7. You are ready to print.

Filament Sensor "Finda"

The filament sensor in the MMU is called "Finda Probe''. This is a metal detecting device. A small non-magnetic steel ball located near the finda sensor in the filament tube in the selector is moved upward when filament passes through the selector. The electrical value of the Finda probe changes from "0" to "1" when the ball is closest to the sensor tip. This informs the printer that the MMU has loaded filament. [2] [3] [4]

Filament Sensor Adjustment.

Proper adjustment of the filament sensor is an important part of tuning the MMU because it is used to control movement of the filament between MMU and extruder. To make this adjustment, the sensor probe fitting is loosened and the threaded tube of the sensor probe can be moved up and down. The goal is to have the Finda probe value read 0 when there is no filament, and "1" when there is filament in the selector tube. A filament offcut inserted in the front of the selector is used to test each condition.

The value of the Finda probe is found either using the telltale LED, or via the Printer firmware menu option: Support > Sensors.

[2] The metal tube that houses the Finda also houses a telltale LED located near the top that informs the user when the filament is triggered. However unfortunately this LED cannot easily be seen when looking at the MMU from the front of the printer.

[3] During MMU operation, it can happen that when a filament is unloaded from the extruder back into the MMU on a filament change, the end of the filament has a string of wispy filament on the end. This can cause misoperation of the Finda mechanism. The Finda is falsely triggered to a "1" condition by the filament string. When this occurs, the MMU LED's may all start to flash, because the MMU thinks that the selector is blocked and cannot move. When that occurs, the user must open the idler lid, pull out the filament and trim the end off. It may also be necessary to apply compressed gas into the selector entry tube or finda-ball viewport to clear out the filament string. The MMU must then be rebooted to clear the error condition.

[4] A 3rd party enhancement of the MMU available on "printables" is to replace the selector with one which houses a holder slot for a magnet and replaces the non-magnetic ball with a magnetic version. The magnet attracts the ball towards the bottom of the filament path more strongly, to overcome effects of fine strings passing through, thus negating some of the effects of filament end-strings that can otherwise cause incorrect finda operation.

Feeding filament from MMU to extruder

During the printing of a model, the Einsy main MCU reads the gcode file supplied by the user line by line.

- When gcode indicates that it requires filament to be fed into the extruder, it communicates to the MMU MCU and commands it to load the specified filament. [5]
- The MMU MCU operates the idler stepper motor to rotate the idler shaft into the drive position for the selected filament.
- The bearing on the idler shaft presses filament into the driving groove in the bondtech gear.
- The MMU MCU then operates the bondtech drive stepper motor to rotate all of the bondtech gears at the same time. Only the filament in the selected gear moves forward.
- The filament travels through the selector, moves the steel ball upward and triggers the finda sensor.
- The MMU MCU sends a signal to the Einsy telling it that the filament is on the way.
- The MMU MCU continues to drive the filament through the PTFE tube that goes to the extruder. When the filament reaches the extruder it enters the extruder drive chamber.
- filament travels into the extruder bondtech gear channel and pushes the extruder idler gear outward. The idler door rotates anti-clockwise on its pivot and the attached vertical extension bar.
- The tip of the extension bar has a “flag” that blocks the beam of infrared light in the IR filament sensor and changes the signal from 0 to 1. This signal is sent to the Einsy MCU, indicating that filament has arrived.
- The Einsy MCU controls the extruder stepper motor to pull the filament into the hot end of the extruder via the internal PTFE tube.[6]
- The MMU MCU controls the idler to release the filament. The movement of the filament is controlled by the extruder filament drive. The drive pushes the filament to the nozzle through the heat break towards the nozzle, and the filament begins to melt. The einsey then reads further gcode commands to continue the print.

[5] The Ensey firmware also provides a menu command “load filament to extruder” that accomplishes much the same thing.

[6] In order to feed properly through the MMU, PTFE and extruder entry, the end of the filament must have a shape that will not snag against small obstructions in the pathway. For this reason, the user is advised to cut the end of a new filament into a “V” shape that allows it to more easily slide past any obstructions. A filament that has already been used to print will have a conical end that accomplishes the same goal.

Extruder adjustments relevant to MMU usage

Extruder Idler Adjustment

The extruder idler bondtech gear applies pressure on the filament as it enters the extruder, which pushes the filament against the teeth of the extruder Bondtech drive gear. This allows the drive to engage the filament and control its movement in and out of the hotend.

The idler gear is attached to the idler cover, and a spring loaded screw is used to adjust pressure applied to the filament. The screw is inserted on the left side of the extruder and the end of the screw is of sufficient length to reach the idler cover embedded nut on the right side of the extruder.

A standard adjustment used for all 1.75 mm filaments (with exception of TPU **) is to tighten the screw until the head of the screw is level flush with the extruder body. A check on this is that the end of the screw should be level flush with the hex hut embedded on the idler cover door.

**The softer TPU filament must have idler screw tension reduced for reliable operation.

When filament is loaded between the drive gear and the idler, the idler cover door rotates on its pivot in an ACW direction (outward).

Extruder IR filament Sensor Adjustment

The purpose of the extruder IR filament sensor is to inform the Einsey MCU that filament is in the entry point to the extruder. This information is used to coordinate operation of filament drives in MMU and extruder. It is also used to detect errors in filament movement.

The IR filament sensor (with MMU installed) is installed at the top of a ‘chimney’ atop the extruder. An arm extends from the idler cover door into a slot adjacent to the IR sensor. A flag at the end of the arm actuates the IR sensor. When the idler cover door rotates due to insertion of a filament, then the flag passes between the IR LED in the sensor, blocking light passing to the IR sensor. This causes the signal state of the sensor to change from 0 to 1.

When filament is removed from the idler, the idler cover rotates in CW direction and the flag end of the sensing arm moves outward and allows light to pass from IR LED to IR sensor. This sets the sensor state to 0.

The IR sensor can be adjusted by moving the chimney in a left-right direction. The user must adjust the position (by loosening two screws) of the IR sensor to attain correct operation of the sensor. The logical state of the IR sensor is displayed when the user accesses firmware menu support > sensors.

Printing Operation (in brief)

The Einsey MCU reads the gcode file and interprets the instructions to drive the X, Y and Z stepper motors to move the bed and the extruder to the required relative position. The extruder stepper motor pushes filament into the hot end, which melts the filament. The melted filament extrudes from the nozzle at a rate that is determined by the pressure applied by the bondtech drive gear. The amount of pressure is determined by the filament volume requirements specified in the gcode.

The extruder stepper motor rotates in reverse (ACW) to pull the filament from the hot end when the filament flow is required to cease.

It rotates forward (CW) to push the filament towards the nozzle when filament flow is needed. It can apply a varying amount of force to the filament to increase or decrease the filament flow rate. This determines the width of the extruded filament.

Changing filaments

When a filament in the hotend is withdrawn, it may have a string on the end, depending on nozzle temperature and filament type. Correct operation of the MMU requires the filament end to be conically shaped having no string. This allows the filament to be correctly sensed and controlled by the MMU.

When gcode indicates a new filament is required, the Einsey commands the extruder stepper motor to move the filament back and forth in the hot end in accordance with “cooling moves” and “ramming” parameters. At the same time, the extruder extrudes onto the “wipe tower”.

Cooling Moves

This is a PrusaSlicer advanced setting that controls slow movement of the extruder and filament drive that is designed to facilitate correct shaping of the filament end.

Ramming Speed

This is a PrusaSlicer expert level setting that controls the amount of filament that is moved forward to shape the end. It works with Retraction to provide an opposing force.

Retraction Amount

This is a PrusaSlicer setting that is normally used to control the amount of filament that is pulled away from the hotend for the purpose of stopping filament flow. It is relevant to MMU operation because it provides a counter to ramming, allowing for repeated attempts to shape the filament end.

Wipe Tower

When filaments are changed, there will be some of the previous filament left in the extruder hotend when the new filament is loaded. The extrudate semi-liquid filament at that time will be a mixture of both filaments. This mixed filament, when extruded onto a model, is called “color bleed”, which is undesirable.

The “wipe tower” is created automatically by the slicer software using inline gcode instructions. The wipe tower is a place where mixed-color filament can be deposited instead of the model. A specified amount of new filament is extruded to clear the old filament from the hot end.

Instructions are also inserted before the filament changes to conduct filament end-shaping and to purge old filament.

MMU Filament Change Operations

When the old filament has been purged, and end-shaping moves have completed:

- The extruder stepper motor pulls the old filament out of the hot end and through the extruder entry channel.
- The idler moves to the left, the idler door rotates CW and the extruder IR filament sensor value changes from 1 to 0. This is the signal for the Einsey to send instruction to the MMU to unload the filament.
- The MMU bondtech drive pulls the filament upward through the PTFE tube and back into the MMU body, and it travels past the finda sensor.
- The finda sensor changes from 1 to 0 and this indicates the filament has returned. (See also footnote 3 above.).
- The end of the filament is moved into a location in the filament path PTFE between the drive gear and the selector, out of the selector movement path. But, due to filament-end strings this position may sometimes be inaccurately calculated by the MMU MCU. (See footnote 7).
- The length of filament that is withdrawn from the extruder is stored in the filament buffer. The buffer is used to prevent tangles in the filament.
- The MMU MCU registers that it can move the selector to the next filament position without jamming.
- The MMU MCU operates the selector stepper motor to move the selector to the new filament position.
- When the selector is in position, the idler motor rotates the idler shaft and the selection bearings move into position to drive the new filament.
- The MMU MCU operates the filament drive stepper to pull/push the new filament through the selector, PTFE and into the extruder as before.[7]

[7] As noted in FN 3, if the MMU MCU senses that filament has not retracted properly, it will flash all of the 10 LEDS to indicate a jam. User intervention is required to clear the jam. filament may be stuck in the extruder through :

- incorrect sequencing/coordination of filament drives,
- slippage of bondtech gears trying to retract the filament
- the end of the filament may have a fat end, making it slow or difficult to retract through the PTFE tube. See also (8) below.

In those cases, user intervention is required to determine the actual cause of the issue. The diagnostic functions of the MMU do not help the user to determine the cause of the problem.(but should do so).

In a typical scenario, the user must open the extruder idler door to free the filament jam, then remove the PTFE tube, pull up the filament and trim the end, before manually pulling the filament back into the MMU (into loading position between bondtech chamber and selector).

In the case where incorrect sequencing of filament drives has occurred, the MMU bondtech gear may have ground a cut into the side of the filament. This possibility must be checked by the user when determining where to trim the end of the filament.(the ground piece must be cut off).

- When the new filament has been loaded into the extruder, gcode commands cause the extruder to begin operation of priming moves. In this operation (described previously under “Wipe Tower”) , new filament replaces the old filament and any mixed filament is extruded onto the wipe tower.
- When sufficient new filament has been extruded, the extruder is moved to the starting position on the model, and printing resumes.

End of the print

The last gcode command to be executed in the model file will normally instruct the extruder to be purged as in “changing filaments” above, and filament is retracted into the MMU as before.

The extruder is moved to the home location and the printer goes into idle mode. The heating of the nozzle and bed are ceased and temperatures slowly return to ambient conditions. The print can then be removed from the bed.

The user can re-roll the filament.[8]

Typically users may choose to immediately put filaments into a drying machine or into dry cabinet storage. It is noted that long-duration prints in humid conditions may have caused filaments to become damp during the course of a print, thus drying is recommended. There is increased risk of this occurring in tropical or in locations near bodies of water.

[8] If the filaments have fattened ends greater than about 1.9 mm, they can be difficult to remove from the MMU. Many Users have found that it is beneficial to increase the inside diameter of PTFE tubes from 2.0 mm to 2.5 mm, allowing the re-rolling of filaments to be done without difficulty. It is recommended that Prusa consider increasing the standard size of these tubes based on user experience.

Maintenance, Faults and Recommendations for Improvement

Previously noted are the following faults often found in the MMU design:

1. Filament Buffer.

   The Prusa standard filament buffer is difficult to use in a dextrous sense and time consuming to load. 3rd parties have designed better options. It is suggested that Prusa consider adoption of one of them or design of a better one. The design goals:

   - Improve ease of feeding filament through the buffer and into the MMU.
   - Reduce footprint of the buffer (it uses too much space).
   - Maintain compatibility with enclosures (Lack and Prusa enclosure).
   - Attach PTFE tubes more securely.
2. Finda Probe: LED telltale.

   The LED is difficult to use for its intended purpose. It could be mounted further up the threaded tube to make it visible from the front of the printer. This would help the user to determine when Finda has triggered.

3. Filament end-strings cause MMU malfunctions:

There are many variants of standard filaments on the market. Users tend to purchase filaments based on price and physical characteristics such as color or finish (eg silk finish), or strength, but not on technical characteristics that affect printing. Manufacturers tend to publish only positive statements about their filaments, not flaws such as stringing and hygroscopicity, so users are unaware of such issues until they buy the filaments and try to use them. And then try all sorts of things to fix the issues when the root cause may be the filament composition or manufacturing quality.

The different filaments have more or less tendency to adsorb moisture and to form strings upon retraction from extruder. But the strings can and often do cause misoperation of the MMU. And it's time consuming and often wasteful of materials to intervene to save prints that have stopped mid-print. Something needs to be improved to make further attempts to solve this issue.

My suggestion:

1. Have the firmware measure the time taken during retraction, until the finda is triggered. The first such reading will be the benchmark. If filament has stringing then the time taken will effectively increase as it takes longer for the Ball to drop during retraction. This assumes filament is not dragging in the PTFE tube.
2. If the time taken increases beyond a threshold (related to the benchmark) then the MMU can decide to cut the filament-end preemptively, before the string causes problems.

This measure would address the **root cause** of the issue using a **pragmatic measure** (of cutting the filament).

2nd Suggestion:

Consider adopting the modification that involves replacement of the finda ball with a magnetic version and a selector having a magnet fitted. This enhancement requires testing by Prusa engineers to determine if it reliably fixes the problem. (Users of Facebook swear it works).

This “fix” may be regarded as a **pragmatic measure** rather than addressing the **root cause**. It looks like formation of the filament-strings is not directly addressed and this could lead to other issues, such as winding around filament drive gears.

3. Correct cutting of the filament end

It seems blindingly obvious, but someone ought to invent a manual filament cutter that applies a proper V shaped cut to the filament end. This could be a modified version of a PTFE tube cutter, with the blade oriented in diagonal direction rather than right angles (square) orientation. A proper cutter would facilitate a consistent shape applied to filaments before printing begins.

When the MMU cutter is used, the filament is cut at right angles rather than the preferred “V” cut. Thus, use of the cutter can cause snagging of the filament that is fed from MMU to the extruder. But it seems to be impossible to design a better cutter that could cut diagonally.

As it is, the cutter seems to work well enough, but cut filament ends can accumulate in the selector. It is possible for this debris to cause misoperation of the selector by impeding its movement. This cutting should be minimized so far as possible. It is better to try to eliminate the root cause of fat filament ends and end-strings. But again, use of the cutter may be viewed as a **pragmatic measure** designed to try to allow continued printing of an MMU model in the face of uncooperative filaments of varying behavior.

4. MMU Diagnostics.

When something goes wrong, the MMU tries to send an error message to the user. Einsey screen says "MMU has a problem". LED's flash, but the user has no clue as to what went wrong or how it should be corrected.

4.1) Suggestion 1: is to consider adding a 2 x 16 character display to the MMU, that provides a textual log of MMU operations and an indication of the actual error condition. There appear to be several connections on the MMU MCU board that could attach such a display.

4.2 2nd Suggestion (Its a long shot):
Background: The Octoprint application running on Raspberry Pi can provide a remote control and monitoring capability for the printer. It is accessible via a web page and local WiFi network. Access can be extended to remote locations by way of 3rd party server connections.

Presently, the Octopi device connects only to the USB connection on the Einsy Board. But it seems plausible that:

a) If a second USB cable were added that connects from MMU MCU USB connector to the Octopi Raspberry Pi,
b) **AND** MMU MCU firmware was modified to output diagnostic information via the USB when its connected (possibly a trigger command might be useful to enable diagnostic mode),
c) **AND** if an Octoprint Plugin were developed that would add a terminal window for MMU and error logging capability.

THEN it would be possible to provide the additional diagnostics capability that is sought, but not requiring attachment of any additional hardware such as a LCD screen to the MMU MCU.

5. Slicer settings.

MMU users should be expressly briefed in MMU user guide on the slicer settings that may require adjustment for an MMU model. Such as temperature, retraction, cooling moves and ramming. (are there any others ?). Similarly, its possible to use the MMU to include soluble filament as support material, but the issue is that a different print temperature may be required for the soluble filament. How can this be set up in the slicer.

Here is a brief summary of the advice I provide to other users in Facebook forums. Is it correct (?)

a) Set correct idler tension on MMU and Extruder.
b) Ensure Finda and IR filament sensors are correctly calibrated.
c) Slicer settings:
   - Retraction: double the normal value 0.8 mm > 1.5 - 2.0 mm
   - Cooling Moves: Increase from default 1 to 3
   - Ramming Distance: Increase from 2.5 mm to 3.5 mm
   - Nozzle temp: reduce by 5 degrees.

6. Other issues: Idler misbehavior.

Many users report issues with misbehavior of the Idler. It can, intermittently, rotates randomly, repeatedly crashing against the end stop and sometimes selects a filament that is different from the selector position. So it feeds filament out of the wrong hole. IN addition, the MCU sometimes resets itself midway during a print.

There are several possible causes to this issue:

(a) Idler body is cracked. Caused by weak design, overtightening of screws.

Cracks on the idler shaft can cause idler movement not to accurately and consistently match rotation of the idler motor. This may cause the idler to reset more often than would occur in ideal conditions.

But what are the possible causes of idler cracking ? Is it a weak design ? Are the screws too tight ? Has the idler motor been resetting the idler with too much force or too often ?

The idler design needs improvement. Perhaps a metal shaft through the whole length of it, with screws at both ends. Perhaps the idler cover hinge needs less free play also.

The current solution is to reprint and replace the idler shaft. Sometimes the crack is found, other times not. And it may be that a root cause electrical issue (see (b)) causes the idler to crash against the backstop repeatedly, causing a crack.

<u>So the cracking may in some cases be considered a symptom, not the disease.</u>

(b) Electrical issue. Vibration or other movement of the MMU wiring loom relative to the MMU MCU connectors results in poor and intermittent connection of the stepper motors, notably the idler motor.

The weight of the wiring loom (many copper wires) is on the end of a lever made up of the (few) flexible connector wires leading to the PCB mounted connector. When vibration occurs the loom can rotate the lever causing the female connector to wiggle against the male pin receptacle on the board. There is no means provided to secure the loom from wiggling in this way.

This is a root cause. It ought to be recognised by Prusa, and fixed as a high priority.

Proposed Solutions (more than one may be applied to cover multiple potential causes):

- (assuming the issue is caused by tin plating of the female pins on the idler motor connector) : Get the manufacturer of the motors to use gold plated female pins instead of tin plated pins. Yes, they cost (pennies) more.
- Apply Deoxit contact cleaner (type D) and contact protectant (Type G) to the connectors. This has been found to work, but it is likely to be a temporary fix. Can Deoxit be included on the Spares offered by Prusa through the online shop ?
- (assuming the cause is vibration of the wiring loom): Provide secure fixing for the wiring loom so that it does not vibrate relative to the MCU PCB causing eventual intermittent failure of the connection. There is currently no place to tie the wiring loom to the body.
- (assuming the cause is vibration). Mount the MMU on the enclosure rather than on the printer. That way vibrations caused by simultaneous operation of Y and X motors during infill operations are not transmitted to the MMU via the printer frame.
- Apply “debounce” logic in the firmware to signals from the stepper motor drivers.
- Reduce vibration of the printer frame.

7. Other issues: MCU Instability Via Low 5V supply rail

Low 5 volt rail voltage on MMU MCU board measured at 4.2 volts is less than required for 16 MHz operation of ATmega32u4 MCU. This can cause misoperation and unexpected resets of the MCU. If clock timing is used for any parts of MCU firmware then such code may not be operating as expected by the developer. This should be investigated by way of code analysis.

What seems to be required is a review of the board design with a view to increasing the 4 Volt rail to at least 4.8 volts, to allow reliable operation of the MCU.

There would need to be two solutions provided for customers: (a) replacement of the MCU Board, and (b) provision of an external plugin board.

It is also noted that connection of an Octopi Raspberry Pi device to the MCU Board via USB connection might lend additional support to the 5V rail on the MCU board, and the possibility of Octopi USB connection needs to be taken into account in devising the solution if it is decided to go ahead with the suggestion offered for Diagnostics via Octopi connection suggested earlier.

8. Other issues: Idler adjustment and ease of use.

As it stands, the idler cover tension screws are used for two purposes,:

- Adjustment of the pressure applied to idler bearings onto the filament
- Holding the idler cover closed or opening of it to allow access for filament loading.

This means that careful adjustments made to the idler tension can be upset by opening the cover for access to the filaments for feeding etc. So the idler tension must be reset each time the filament is changed.

My suggestion is to invent a more sophisticated and user friendly way to secure the cover. The desired characteristics:

- Easy to open and close cover for access to the filaments
- Without changing the idler tension adjustment.

The suggestion is to design a single “over center” style of clip that separates the function of idler tension adjustment from the action of opening and closing the lid.

I can imagine the design but do not have the resources to develop it.

9. Other issues: Printer access for servicing and removal from enclosure.

Adding the MMU onto the printer entails PTFE tubes going outside of the enclosure.

The MMU connects to the Einsy MCU Board using wiring which is attached to the MMU wiring loom.

These two external connections tie the printer to the enclosure in which it is normally mounted, and tie the MMU to the printer. The printer cannot easily be removed from its enclosure and the MMU cannot easily be removed from the printer for workbench repairs, servicing and adjustments.

If the MMU is removed from the printer, then removal of the PTFE tube means that wiring connections must be disturbed. This can initiate issues with intermittent erratic idler operation.

The printer can encounter issues such as the need for hotend or nozzle replacement or attention to bearings which is easier if the printer is moved out of its enclosure and onto a workbench.

So, two enhancements are proposed to address these issues.

(a) Addition of Festo style connectors onto the ends of the PTFE tubes leading to filament buffer. This would allow the tubes to be more easily removed from the MMU, without disturbance of the MMU wiring loom.
(b) Addition of a set of electrical connectors inline with the Einsey cables allowing the MMU to be quickly disconnected and removed from the printer and enclosure.

10. User Satisfaction Survey

It is surely time that some objective light was shed on the overall question of MMU reliability and usability. A ‘quality metric’ survey of user satisfaction should be conducted, which may inform Prusa’s decision to implement fixes for the most significant issues of concern.

11. Expert Fault recording and Analysis System

It is possible to imagine a software based fault analysis tool that might take a user through a series of observational steps to arrive at standard correctional recommendations. Such tools are not difficult to build. They require input from experienced support staff and users in order to collect information that would inform the design of the tool.

The tool would deliver to the user common solutions to common experiences. (The user may be unaware that their experiences have often been encountered by many other people.)

The business benefit of such a development is that such a tool would encourage a user to record their symptoms to the benefit of greater accuracy, objectivity and productivity when dealing with Prusa Support. Such a tool may also include places for a user to upload photographs and videos showing evidence needed by support staff to visualize issues.

During operation, the tool can collect statistics on common issues, which can be statistically analyzed, and this may inform management decisions on prioritizing any needed engineering work.

Legal

Prusa have devised the MK3S/+ printer and MMU as their own product, but having an open-source design. It has similarity to printer products devised by other manufacturers according to the “RepRap” design pattern.

The MMU appears to have been designed to fit a price range, having basic functionality, but lacking “bells and whistles”. Users have been encouraged to develop their own perceived necessary enhancements.

Prusa may be reluctant to adopt MMU enhancements devised by users for fear of legal action (particularly from the US and Europe) that would demand payment on the basis of intellectual property rights.

The author (not having legal qualification) suggests that the open source nature of the MMU design and of many of the user enhancements may tend to negate the risk of legal demands based on IP rights.

However Prusa might still see their way clear to reward customers that have devised popular and effective remedies in some way, such as store credits. And Prusa may choose to acknowledge users that have contributed to the product in written material that may accompany the product.(this is necessary by way of the copyright declarations in common use. (such as ‘creative commons’)