

# Mechanical finger prosthesis design and manufacturing by modern technologies

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**Abstract:** The article deals with the use of CAD software and additive technology to produce a simple, low-cost mechanical finger prosthesis. The goal was to use SOLIDWORKS and Cura software to design and manufacture an index finger prosthesis from PLA (polylactic acid) material, using an FFF (Fused Filament Fabrication) desktop 3D printer Bq WitBox. The mechanical finger prosthesis is used for flexion and extension performance of the missing joints to enable lost gripping function. The designed prosthetic finger has a simple construction consisting of components made on a 3D printer and its movement functions are initiated by specifically attached cable system. The practical part of the paper contains procedures for prototype and final version design, manufacturing and testing. The prototype was designed to imitate healthy finger digits movement initiated by the specific cable system. Final version of the finger prosthesis has been designed after the successful flexion/extension system testing. The design of the components was modified to resemble a healthy finger and a socket has been added to the prosthesis. Flexion and extension performance of the prosthesis was tested using cables of different diameters. After summarizing the results, it has been confirmed that the prosthesis can be easily applied to the arm and its dimensions, construction and movement correspond to an anatomically healthy finger and that 3D printing is a technology suitable for efficient and fast production of individual prosthesis components, which is an indisputable advantage compared to the traditional method of prosthesis production.

**Keywords:** FINGER PROSTHESIS, ADDITIVE MANUFACTURING, FUSED FILAMENT FABRICATION

## 1. Introduction

The human hand is one of the most important organs for man, since it distinguishes us from other animals. The reason for this uniqueness is that it can oppose the thumb, which allows it to manipulate objects and perform precise grips. Arms and grasps are very important for everyday activities such as eating, hygiene, dressing and the like. The powerful elements during the individual phases of gripping are the fingers and thumb. In case of their injury, illness or amputation, the performance of normal motor activities is considerably complicated or completely impossible. Prosthetic finger replacements made by additive manufacturing can solve these problems. The article describes the design and methodology of prosthetic finger production using modern technologies.

## 2. Methodology

The aim of the work was to create a functional mechanical finger prosthesis that will allow flexion and extension in the PIP (proximal interphalangeal) and DIP (distal interphalangeal) joint. The reason is the amputation in the proximal phalange and thus the absence of the possibility of performing grips. Before designing the prosthesis, itself, it is necessary to clarify what movement functions of the arm need to be replaced and in what most suitable way it can be realized.

One of the most important tasks is to ensure that the prosthesis matches in the size parameters of the finger joints, as well as in their movement paths [1].

Prosthesis design phases:

- Design, 3D modelling and printing of a prototype.
- Assembly and functional testing of a prototype.
- Design, 3D modelling and printing of the final version
- Folding, application of the final prosthesis and testing

## 3. Solution

### 3.1 Design, 3D modelling and printing of a prototype

The construction of the prosthetic finger movement chain model consists of four artificial phalanges connected by joints, which represent the individual phalanges and joints of the index finger, including the MCP (metacarpophalangeal) joint, which is the most proximal in this chain. The functionality of this model is ensured by the application of a cable system passing through the individual finger joints and phalanges and is anchored proximally to the MCP joint, which is the driving element bending the prosthesis components [2, 3].

Through a specially designed system of channels and holes in the prosthesis, the cables serve to initiate flexion and extension in the PIP and DIP joints (Fig. 1). Bending the MCP joint lengthens the distances A, B and shortens C, D, which causes flexion in the PIP and DIP joints [4, 5].

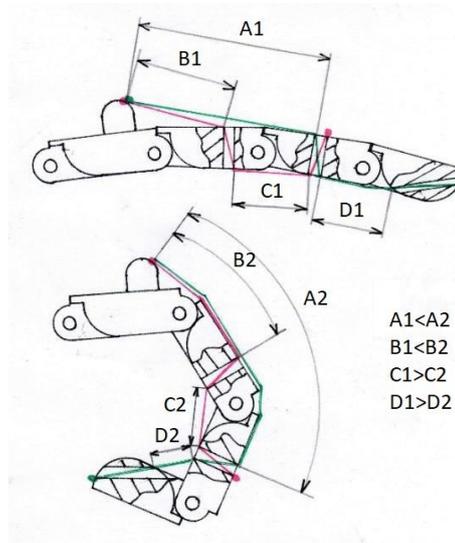


Fig. 1 Design of a prosthesis cable system.

All components have been designed in SOLIDWORKS (Dassault Systemes, Waltham, USA) software. Parts of the prototype were printed in a larger scale, for easier handling and the design is simplified.

The design of the prototype consists of eight components (Fig. 2), which are:

- 1x fingertip (distal joint),
- 3x phalange,
- 1x anchorage (for fixing the cable system),
- 3x peg (articulated connection)

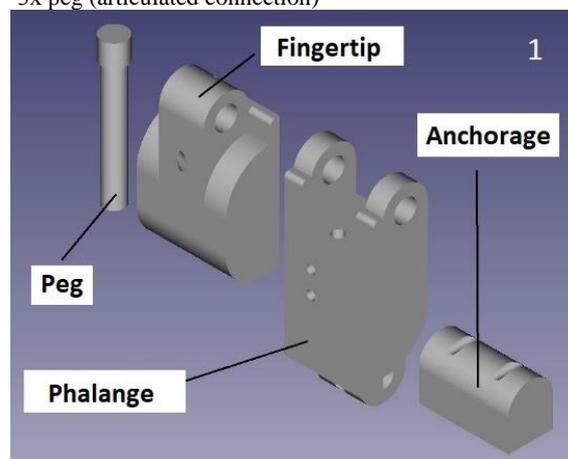


Fig. 2 Prosthesis prototype components.

The individual components of the prosthesis were manufactured on a Bq WitBox (bq Engineering, Madrid, Spain) 3D printer. This printer allows printing of large objects or multiple components at once. It is a fully enclosed printer with a front door locking system that prevents accidental access during printing. Its fully enclosed design helps minimize noise, while preventing heat leakage and maintaining a constant temperature inside the printer.

Bq Witbox is an FFF printing system, which means that a fibre of material leads through a Fibonacci guide tube into the nozzle. Due to this design, the feeder system remains inside the printer unit, thus reducing the amount of contact between the fibre and the tube.

The material used to make the prosthesis is PLA (polylactic acid) and the software used to set the printing parameters was the Cura (Cura Global GRC Solutions Pte Ltd., Singapore, Singapore) software.

Cura is a software that prepares and converts 3D computer-generated models into commands that follow the printer.

After positioning the model on the working platform, the software allows setting individual printing parameters, such as layer thickness, object fill density, print speed, nozzle temperature, support and thickness, or fibre flow (Fig. 3).

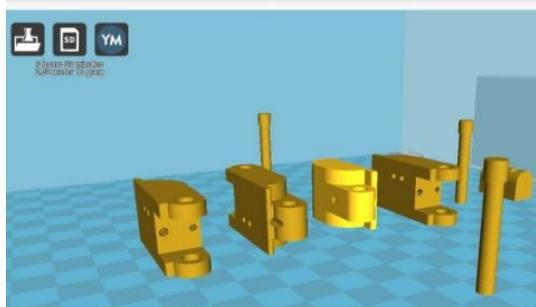


Fig. 3 Positioning models on a work platform.

Selected print parameters:

- Layer height = 0.1mm.
- Shell thickness = 1mm.
- Bottom / top wall thickness = 0.5mm
- Infill density = 10%.
- Print speed = 50mm / s.
- Without support.

After setting the individual parameters, the software automatically determined the length of the printing time (3h 38min.), the weight of the material used (18g) and the length of the fibre used (2.32m).

### 3.2 Assembly and Functional Testing of the Prototype

After 3D printing, the parts are carefully separated from the printer's work platform and are thoroughly cleaned. Another important step for the successful assembly of the prosthesis is postprocessing, i.e. grinding of all parts of the prosthesis, especially in places where the individual components meet residual support material. Thorough treatment of the components is followed by the assembly phase of the prototype prosthesis.

In the proposed model, the finger phalanges are connected by pegs in the DIP, PIP and MCP joints. The anchorage on which the rigid cables will be attached is attached to the proximal phalange, just behind the MCP joint (Fig. 4). In forming the extensor system, a knot is tied at one end of the elastic cord and the free end is threaded through an opening at the end of the distal member that extends through the entire component. In this way, it is passed through the individual links of the prototype and secured at the end of the proximal link. To create a flexor DIP joint system, it is necessary to knot one end of the rigid cable and pass the free end through the hole at the end of the distal phalange. The free end is removed from the hole on the palm side and then passed through the hole on the palm side on the next link, after which the end of the cable is attached to the anchorage. To form the flexor system of the PIP joint, one end of the rigid cable is knotted and passed through the dorsal opening of the cavity on a phalange proximal to the tip of the prosthetic finger. Subsequently, the cable is passed through the

palmar opening of the cavity on the more proximal phalange and the end is fixed to the anchorage [6].



Fig. 4 Finger prosthesis prototype.

With the applied cable systems, the prototype of the prosthesis is fully functional, i.e. flexion in the MCP joint induces flexion in both the PIP and the DIP joint (Fig. 5). After performing a functional test of the prototype, the production of the index finger prosthesis with a socket and an anatomically more accurate design continued.



Fig. 5 Functional testing of the prototype.

### 3.3 Design, 3D Modelling and Printing of The Final Version

In the final phase of the design of a prosthetic finger, it is also necessary to consider the aesthetic function. For this reason, it is necessary to emphasize the appearance, dimensions and shape of the socket. The prosthesis must resemble an anatomically correct index finger as much as possible, i.e. its dimensions and the location of the joints must correspond to the parameters of the original index finger. To obtain the most realistic finger, it is advisable to use the mirroring of the preserved healthy arm, as it is a paired organ.

The prosthesis socket is one of the most important parts of the prosthetic system and must not restrict or prevent the movements of the thumb and middle finger of a healthy arm. Its circumference must not differ significantly from the circumference of the stump in order to ensure its best possible attachment. Since the prosthesis will be hung on a wooden hand, a socket with the same inner circumference as the circumference of the artificial stump has been designed to make the suspension of the prosthesis as strong as possible. A sleeve has not been used.

The individual components of the prosthesis have a cylindrical shape, on the dorsal side they are equipped with stops that prevent the prosthesis from performing hyperextension, and a special system of cavities and ducts inside the prosthesis parts through which the cables will pass has been designed [7].

The construction of the final finger prosthesis (Fig. 6) consists of:

- 1 x fingertip (distal link),
- 1 x phalange (medial link),
- 1 x phalange with socket (proximal link),
- 1 x anchorage (for fixing the cable system),
- 2x peg (articulated connection)

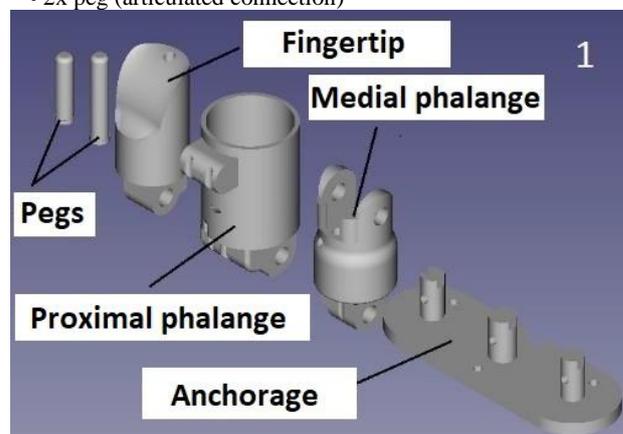


Fig. 6 Components of the final version of the finger prosthesis.

The material, production technology and process settings of the

final prosthetic finger are identical to the prototype (Fig. 7). Only the colour of the material has changed.

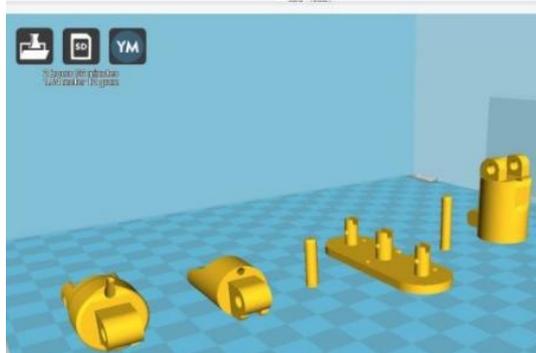


Fig. 7 Positioning models on a work platform.

Result of saving models in the Cura software:

- Print time length: 2h 36min.
- Weight of material used: 12g.
- Length of fibre used 1.54m.

### 3.4 Folding, Application of the Final Prosthesis and Testing

The procedure for assembling a prosthetic index finger is identical to the procedure for assembling a prototype prosthesis. It is important to thoroughly clean all components of unwanted residual material and, if necessary, to grind the areas where the individual components come into contact. Subsequently, the prosthesis can be built.

By connecting the distal and medial phalange with a shorter peg, a DIP joint is created. The same connection of the medial and proximal phalange with the longer peg creates a PIP joint. The constructed prosthesis is placed on the stump and the cable systems is inserted (Fig. 8).

While forming the extensor system, an elastic cable is used which has a knot at one end and the free end is threaded through an opening at the distal end of the socket. Next, the cable is guided through a cavity on the dorsal side of the medial phalange and subsequently through a cavity on the dorsal side of the distal phalange, at the end of which is the second knot.

Since the functionality of the double flexor system was confirmed during the prototype's testing and this system proved to be suitable, it is also applied in the final version of the prosthesis. To create a flexion in the DIP joint, a rigid cable is used, at the end of which there is a knot and the cable is guided through a distal opening on the distal phalange and subsequently the cable is threaded through it. The cable is further passed through the medial phalange through an opening in the distal part. A rigid cable was also used to form the flexor system of the PIP joint, at the end of which there is again a knot and the free end is guided through an opening on the dorsal side of the medial phalange. The cable emerges from the palmar opening and is threaded through the opening on the distal side of the socket, passing crosswise through the bottom and through the opening on the dorsal side.



Fig. 8 The final version of the finger prosthesis.

In places where the cables meet the edges, grooves have been

formed on the prosthesis' components to minimize friction and to prevent rigid cables from protruding from the prosthesis. This modification reduces the risk of damage to the cable systems and improves the contact of the prosthesis during the gripping of objects.

The cable system anchoring component is attached to the dorsal part of the palm of the wooden hand by means of two small cross screws proximal to the MCP joint to secure the cable systems as firmly as possible. When attaching rigid cables for anchoring, it is necessary to position the prosthesis in its end position, i.e. in the position in which the tip of the prosthetic finger touches the palm of the hand model. When the finger is in the given position, the cables are the most tensioned and are firmly knotted on the pins of the anchoring component. The cables are attached to two different pins (PIP joint bender on the left and DIP joint bender on the right), in order to make the tension adjustment as simple as possible and to prevent accidental tangling of the individual cables.

### 3.5 Finger Prosthesis Testing

After the assembly of the final prosthetic finger, the phase of its functional testing follows. To verify the effectiveness of the flexion of the finger prosthesis in order to design its modifications or correction, it is necessary to monitor the course of individual phases of this movement.

Prosthetic finger flexion phases (Fig. 9):

- Phase 1 (zero position / extension),
- Phase 2 (flexion of MCP, PIP and DIP joint),
- Phase 3 (flexion of MCP and PIP joint, DIP joint is in the maximum possible flexion),
- Phase 4 (final position - MCP, PIP and DIP joints are in the maximum possible flexion)

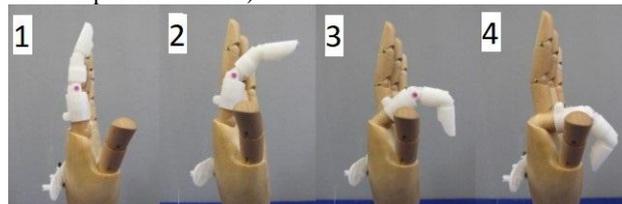


Fig. 9 Stages of finger prosthesis flexion.

## 4. Results and Discussion

Performing complete flexion in the MCP joint revealed, that during the transition from the 3rd to the 4th phase, the cable system of the DIP joint is deployed and the cable rubs against the lateral side of the MCP joint, and that the fingertip does not touch the palm of the hand model.

The first problem was eliminated by creating 2 cavities directly through the protrusion on the dorsal part of the socket, through which the rigid cables are passed, and the cable system of the DIP joint is attached to the more medial pin of the anchoring component. This removed the unwanted dislocation of the cable from its original bearing.

To solve the 2nd problem, different diameter of cables were applied (see Table 1) and the course of flexion in individual phases was documented.

Table 1. Cable types

Cable	Diameter (mm)	Load capacity (kg)
Cable 1	0,22	5
Cable 2	0,36	14
Cable 3	0,50	18

When using cable 1, there was no flexion in the PIP joint of the prosthesis and flexion in the DIP joint is incomplete. This diameter is not satisfactory. The application of cable 2 has improved the

flexion in both joints of the prosthesis, but the flexion in the PIP joint is incomplete and in phase 4 of the prosthesis flexion the fingertip does not touch the palm of the hand model. Using cable 3, the flexion in the joints of the prosthesis is complete and the fingertip touches the palm of the hand model (Fig. 10).

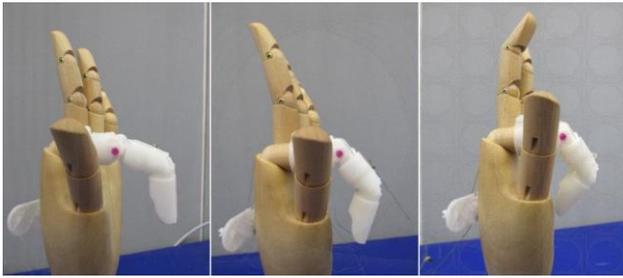


Fig. 10 Testing of the prosthesis cable system.

As shown on the procedure above, for selecting a suitable type of cable that the diameter of the cable has a significant effect on achieving the desired finger flexion. This is caused by different plastic deformations of different types of cables.

### 5. Conclusion

The aim of this article was to design, build and test a functional mechanical index finger prosthesis with components made by additive manufacturing. The design of the proposed prosthesis resembles an anatomical finger and its movement mechanism is simple and effective. The prosthesis can be easily applied to the arm and its dimensions and construction correspond to an anatomically healthy finger. 3D printing is a technology suitable for efficient and fast production of individual prosthesis components, which is an indisputable advantage compared to the traditional method of prosthesis production.

In the future, the application of sleeves is being considered, for which it is appropriate to upgrade the prosthetic finger. The reason is to improve the aesthetic function and obtain a more natural look, as well as to improve the functionality that can be achieved by applying anti-slip sleeves to increase the certainty of performing the grip. It is necessary to design a glove in which the cable systems of the prosthesis will be anchored, without limiting their functionality.

### 6. Acknowledgments

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