

# APPLICATION OF QFD TO MECHANIZE THE MANUFACTURING OF THE JAIPUR FOOT

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The current manufacturing process of the Jaipur foot involves laborious, repetitive and non-standard techniques. Most of the process steps involve manual trial and error methods. This results in considerable variability in the quality of the end product, high reject rates and low production volumes. In this work Quality Function Deployment techniques are employed to determine critical fabrication processes that affect the quality of the final product. The identified processes are then replaced with suitable solutions that mechanize the process and ensure repeatability and uniformity. These mechanisms serve to streamline and standardize the foot production process.

*Keywords:* QFD, Jaipur Foot, Process Improvement, Mechanization.

## 1. THE JAIPUR FOOT

The Jaipur foot is a rubber based prosthetic foot for Above-Knee and Below-Knee amputees created in the 1970s [1]. The foot is well-suited to the needs of developing countries because it allows the user to walk barefoot and squat, is waterproof, and very durable. There is a great demand for the foot because of its very low cost but a huge gap exists between demand and supply. Non-governmental organizations (NGOs) such as the Bhagwan Mahaveer Viklang Sahaita Samiti (BMVSS), Mukti India, Gandhigram Trust [2], etc., are involved in producing and distributing artificial limbs at little or no cost to the people who need them.

The foot fabrication process is taught by apprenticeship and through short term training courses. However, the process is cumbersome [3, 4] and quality is hard to ensure, even in the same manufacturing facility. The quality of the end product is very much operator dependent resulting in a large number of defective pieces. Streamlining and mechanizing the manufacturing process to some extent will reduce operator dependency and ensure that a uniform quality is maintained in the foot production and improve productivity.

### 1.1. Jaipur Foot Manufacturing Process

The Jaipur foot consists of three sets of blocks namely, the ankle block, forefoot block, heel block and toes. The ankle block is made of laminated wood. The forefoot block is made of soft Micro Cellular Rubber (MCR). Smaller MCR blocks are first joined together using adhesives. The resulting larger block is then trimmed with a knife and filed to smoothen out the edges. The heel block is made the same way using hard MCR. The toes are cut out from waste MCR pieces. Vulcanized rubber cement is coated uniformly over the blocks. The dried blocks are individually wrapped using cushion rubber. All the pieces are then re-wrapped with tire cord for reinforcement. The foot block comprising all of the components is assembled in the die with layers of cushion rubber and thread rubber underneath.

The whole assembly is then encased in skin rubber and vulcanized in an autoclave to obtain the finished foot. The components of the Jaipur foot are shown in Figure 1.

## 1.2. QFD and its application to Jaipur Foot

QFD is a systematic approach to design [5, 6, 7]. It consists of translating subjective customer requirements into objective engineering specifications which can be quantified and measured. The design specifications can then be used to manufacture quality products and enhance customer satisfaction.

In this work QFD techniques are used to improve the fabrication process of the Jaipur foot. The manufacturing staff are considered as the customers for the process improvements in order to capture the production needs. Raw data was collected based on observations and through interactions and interviews with the production staff in the Jaipur foot manufacturing unit at Gandhigram [2]. The staff response data along with a careful study of the rejects, helped narrow the list down to two critical processes that impacted the most on the final quality of the foot. The House of Quality drawn for the foot manufacturing process is shown in Figure 2. Based on the QFD, the identified processes are the block wrapping and block shaping steps

### 1.2.1. Block Wrapping Process

This process is operator dependent, repetitive, inconsistent and the HOQ showed that it directly affects the quality of the foot. This process required that a uniform tension and overlap be maintained in the cushion rubber strips. A plan to build a wrapping mechanism was created. QFD methodology is repeated for the design and manufacture of the mechanism.

Product Design and QFD methods as applied to the wrapping mechanism:

#### 1.2.1.1 Product Planning

Customer needs are identified and rated. The rated needs are translated to engineering specifications, relationship and correlation matrices drawn and absolute importance of each metric is calculated. The resulting House of Quality is shown in Figure 3.

#### 1.2.1.2 Product Design

The wrapping mechanism has to wrap the strips uniformly over different sized blocks while maintaining proper tension. In order to achieve this, a multi-functional mechanism consisting of an open belt driver and power screw was devised. The components of the wrapping mechanism are: input pulley, output pulley, pillow block bearings, power screw, guiding rod, L-angled frame, V-belt, crank, ball bearing, bolts and nuts.

#### 1.2.1.3 Wrapping Mechanism Assembly

The L-angled section frame is fabricated to house the remaining components of the mechanism. The power screw (490 mm length) is supported on two pillow block bearings and these pillow block bearings are mounted on the L- angle section frame. At one end of 490 mm length power screw, a 2" pulley is inserted. Similarly, a guide rod (195 mm length) is supported on two pillow block bearings and at one end a 10" pulley is inserted. Proper arrangement has to be made to align the two pulleys (right side of the frame). 10mm bolts are used to attach the pillow block bearings to the frame. A 24mm diameter nut is welded to the frame (left side). Through that nut another threaded rod is screwed. The fabricated left jaw is inserted into one end of the threaded rod. Likewise the right jaw is inserted to one end of the plane rod. The CAD model of the assembled mechanism and the built prototype are shown in Figures 4 and 5 respectively.

### 1.2.2. Rubber Block Shaping Process

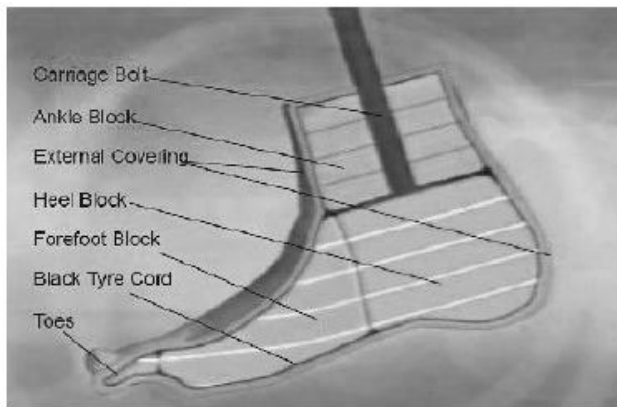
The rubber blocks, when hand trimmed, resulted in non-standard shapes and sizes, uneven cutting and improper finish. The process is also time-consuming because the operator had to check with the template several times to ensure that the shape and size meet the requirements.

The QFD procedure was carried out to identify key design features and a punch cutting mechanism with interchangeable dies was built. The two processes before and after mechanization are shown in Figures 6, 7, 8 and 9.

### 1.3. Results and Conclusion

The manufacturing process of the Jaipur foot utilizes cumbersome, worker dependent and repetitive techniques that make quality control measures difficult to establish. This paper demonstrates the use of the QFD approach to both identify manufacturing processes that could benefit from mechanization and also to identify key characteristics needed in the design of the mechanisms. Employing QFD methods to the processes enabled the identification of two crucial rate determining steps, and these steps were selected for mechanization. The mechanized processes have been sent to Gandhigram [2] manufacturing unit for field-testing and feedback is awaited. Further improvements to the designs will be made based on the feedback. The developed mechanisms are expected to be cost effective replacements of the block wrapping and manual shaping methods thereby enhancing productivity, and ensuring uniformity and repeatability in the manufacturing of the foot.

## 2. FIGURES



**Figure 1.** Components of the Jaipur foot. (Courtesy: [3])

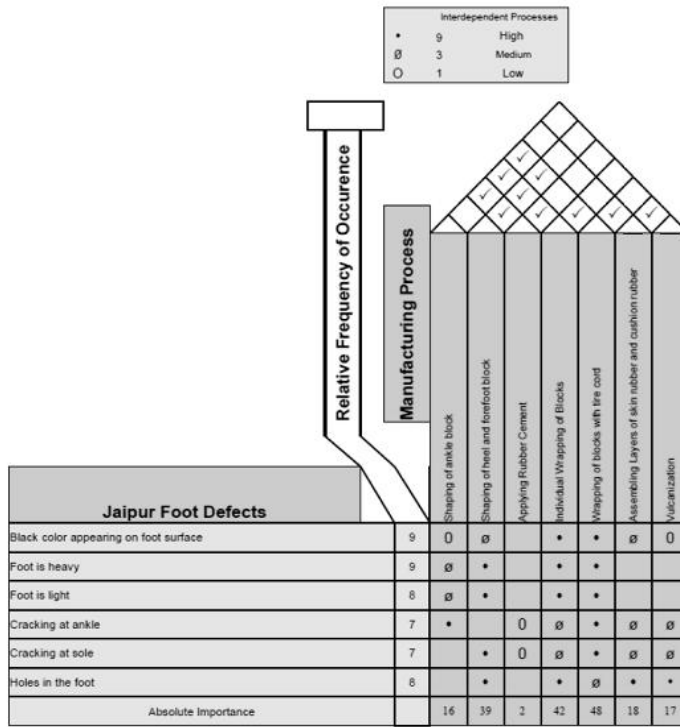


Figure 2. House of Quality (defects) for Jaipur foot.

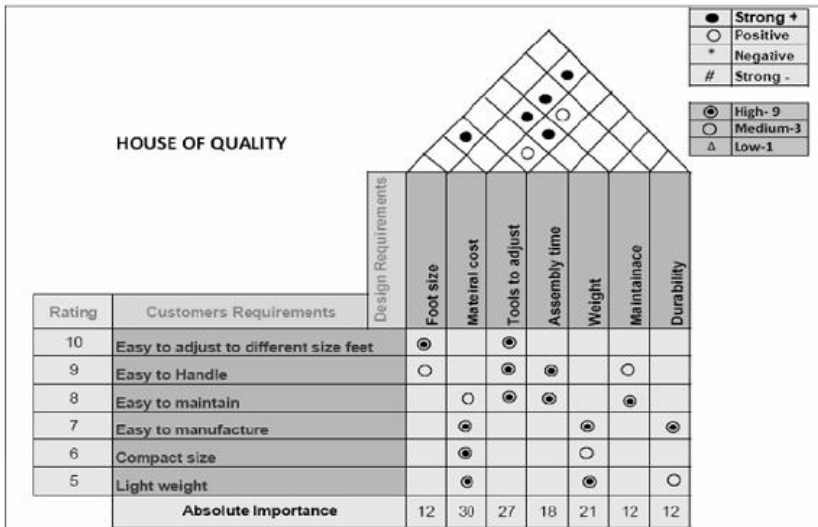


Figure 3. House of Quality for Wrapping Mechanism.

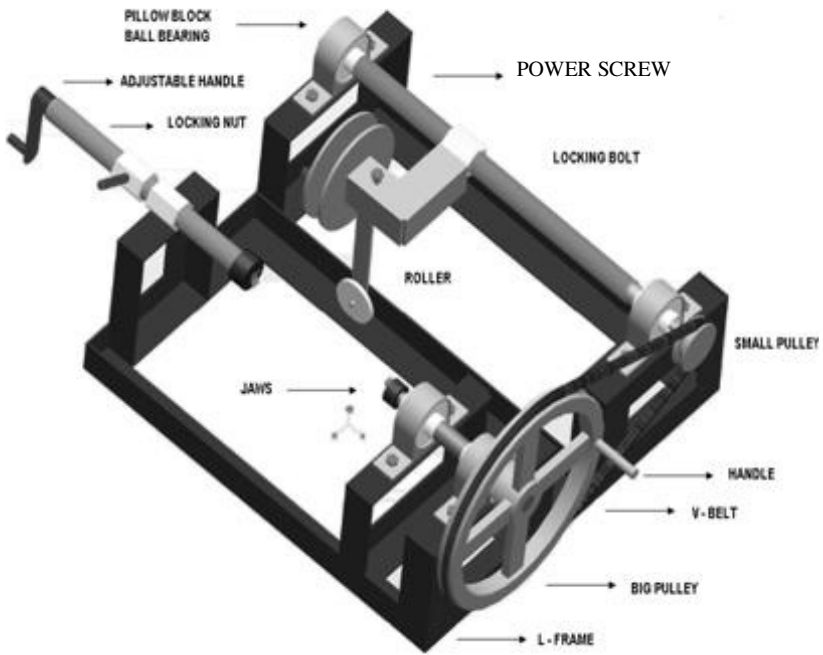


Figure 4. CAD model of Wrapping Mechanism.

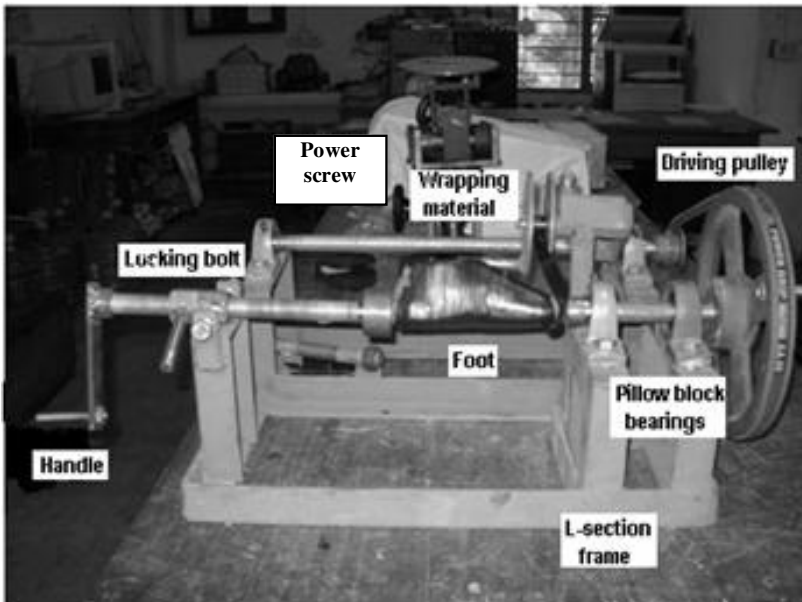


Figure 5. Wrapping Mechanism Prototype.



**Figure 6.** Block Wrapping Process before Mechanization.



**Figure 7.** Block Wrapping Process after Mechanization.



**Figure 8.** Block Shaping Process before Mechanization.



**Figure 9.** Block Shaping Process after Mechanization.

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