Design of calipers for post polio paralytic patients engineering essay

ABSTRACT

Over 13 million in India people suffer from various locomotor disabilities, of which 4 million have been afflicted by polio. Polio destroys the nervous system and causes paralysis of the limbs. An orthosis or brace is required to provide support to compensate for the weakened muscles, maintain proper positioning and stability of the affected joints, restore weight-bearing capabilities to the affected legs and allow the patient to walk without the risk of falls and further fractures.

The objective of this project is to develop a design for adjustable polio braces, taking into consideration hinge movement at the knee. The current designs of KAFO are made of Stainless Steel, Aluminium, Thermoplastics, Reinforced Carbon fibers etc. While Aluminium is light-weight, it does not provide the required stiffness for the caliper design; Stainless Steel is corrosion resistant and has great yield strength but is heavy. Hence material analysis is done to chose a material with density between that of Aluminium and Stainless Steel, but with high ultimate strength and high fatigue endurance limit. Also the currently available designs do not incorporate flexible movement at the knee thus discomforting the patient during travel etc. The proposed design is done using CAD tools. A pilot prototype is made in PVC and field-tested to determine if adjustments can be easily performed by the patient. Based on feedback from the field-testing, the final model was designed using Titanium scraps.

ABOUT THE COMPANY

M/s. AAROPNA PROTESI PRIVATE LTD. is a medical implants & surgical instruments manufacturing and trading company. Our choice of this company was based on its expertise in developing biomedical instruments and implants and its association as a subsidiary of its parent company parent M/s. TITANIUM TANTALUM PRODUCTS LTD, which is an ISO 9001: 2008 certified company dealing in various Titanium Products for the past 29 years.

The objective of the company is to establish the necessary world-class infrastructure for design, develop, manufacture, package, trade & market the Orthopaedic, Neurosurgical, Orthodontic, Dental and other similar reconstructive / replacement implants and its surgical instruments in Titanium alloys and other advanced Biomaterial.

Aaropna Protesi Private Ltd. deals with designing of medical implants through biomechanical laws and the development, customization and optimization of medical implants and instruments using technology of CAD-CAM Solutions. It trades in world-class imported medical implants, surgical instruments, tools & other surgical accessories in India. It has more than two decades of experience in handling Titanium, Tantalum, Zirconium and Niobium through its parent company.

INTRODUCTION

1. 1 WHAT IS POLIOMYELITIS?

Poliomyelitis, often known as polio or infantile paralysis, is an acute viral infectious disease spread from person to person, primarily via the fecal-oral route. [1]

In about 1% of cases the virus enters the central nervous system, preferentially infecting and destroying motor neurons, leading to muscle weakness and acute flaccid paralysis. Different types of paralysis may occur, depending on the nerves involved; spinal polio is the most common form, characterized by asymmetric paralysis that most often involves the legs. [2]

The term poliomyelitis is used to identify the disease caused by any of the three distinct variations of poliovirus. Two basic patterns of polio infection are described: a minor illness which does not involve the central nervous system (CNS), sometimes called abortive poliomyelitis, and a major illness involving the CNS, which may be paralytic or non-paralytic. [1] In most people with a normal immune system, a poliovirus infection is asymptomatic.

The virus enters the central nervous system in about 3% of infections. Most patients with CNS involvement develop non-paralytic aseptic meningitis, with symptoms of headache, neck, back, abdominal and extremity pain, fever, vomiting, lethargy and irritability. [2][3] Approximately 1 in 1000 to 1 in 200 cases progress to paralytic disease, in which the muscles become weak, floppy and poorly controlled, and finally completely paralyzed; this condition is known as acute flaccid paralysis. [4]

In many countries, polio or 'poliomyelitis' was for many years the most common cause of physical disability in children.[1] Currently through vaccination programs, Polio has been eliminated in most countries, a size-able percentage of people are still affected by the crippling disease in India, Nepal, Nigeria and Afghanistan.

Often the paralysis will gradually disappear, partly or completely. Any paralysis left after 7 months, however is usually permanent and certain secondary problems may develop, especially if precautions are not taken to prevent them. These problems are further disabilities or complications that can appear after, and because of, the original disability.

Contracture of joints is one commonly encountered secondary problem. In this there is a shortening of muscles and tendons so that the full range of limb movement is prevented. [5]

Fig. 1. 1 Typical contractures in polio

Other common deformities can cause deformities including over stretched joints and dislocations.

Fig. 1. 2 Deformities caused by polio

1. 2 EVALUATING A PATIENT'S NEED FOR AIDS AND PROCEDURES

Step1: Observe the patient carefully and notice which parts of the body seem strong, and which seem weak. Differences between one side of the body and the other are identified such as differences in the length or thickness of the legs. Other deformities, unusual gait, tilt to one side, supporting limbs, position of hips, shoulder and curve of back are also observed. These early observations will help you know what parts of the body you most need to check for strength and range of motion. [5]

Step2: This is the physical examination. It should usually include:

Range-of-motion testing, especially where there might be contractures.

Muscle testing, especially of muscles that may be weak. Also test muscles that need to be strong to make up for weak ones (such as arm and shoulder strength for crutch use).

Check for deformities: contractures; dislocations (hip, knee, foot, shoulder and elbow); difference in leg length; tilt of hips and curve or abnormal shape of the back.

Step3: After the physical exam, again observe how the patient moves or walks. The particular way of moving and walking is related with the physical findings (such as weakness of certain muscles, contractures, and leg length).

Step4: Based on observations and tests, a study is done to understand what assistance might help the patient. Different aspects of the aid must be considered such as: benefit, cost, comfort, appearance, availability of materials, and whether the patient is comfortable.

Step5: Once the assist device has been decided, the necessary measurements are taken to make the brace or aid. When making it, once again it is wise to put it together temporarily so that adjustments can be made before it is rivet, glue, or nail it into its final form.

Step6: Have the patient try the brace or aid for a few days to get used to it and to see how well it works. If there is discomfort or any problems, alternate improvements or necessary adjustments should be made.

1. 3 DESCRIPTION OF A CALIPER

Braces or calipers are aids that help hold legs or other parts of the body in useful positions. They usually serve either one or both of the purposes given below:

To provide support, strength/firmness to a weak joint (or joints).

To help prevent or correct the deformity.

ORTHOTIC DEVICE:

An orthosis or orthotic is an orthopedic device that supports or corrects the function of a limb or the torso [6]. An orthopaedic brace or orthotic is an orthopaedic device used to:

Control, guide, limit and/or immobilize an extremity, joint or body segment for a particular reason

To restrict movement in a given direction

To assist movement generally

To reduce weight bearing forces for a particular purpose

To aid rehabilitation from fractures after the removal of a cast

To otherwise correct the shape and/or function of the body, to provide easier movement capability or reduce pain. [6]

LOWER LIMB ORTHOSIS:

A lower-limb orthotic is an external device that is attached to the lower limb as a whole or limb segment in order to improve its function by providing support, reducing pain through transferring load to another area or correcting flexible deformities.

NOMENCLATURE FOR CALIPERS

Calipers are named after the joints that they replace the function of. The following are the acronyms used:

Ankle Foot Orthosis (A. F. O.)

Knee Ankle Foot Orthosis (K. A. F. O.)

Hip Knee Ankle Foot Orthosis (H. K. A. F. O.)

ANKLE FOOT ORTHOSIS (A. F. O. s):

Ankle foot orthoses are orthotic devices encompassing the ankle joint and all (or part) of the foot. AFOs are externally applied and intended to control position and motion of the ankle, compensate for weakness, or correct deformities. [6]

Fig. 1. 3 Ankle Foot Orthosis

KNEE ANKLE FOOT ORTHOSIS (K. A. F. O.):

A knee-ankle-foot orthosis provides flexion, extension and mediolateral stabilization of the knee; may provide free or locked knee motion, or adjustable range of motion [7].

A knee-ankle-foot orthotic is typically designed to enable patients suffering from weakness or lack of control of the knee joint to walk safely. It is also used as an independent walking device for a walking-impaired person whose lower limb is paralyzed or whose muscle function is lost due to his spinal cord injury, diseases (such as polio), cerebrovascular disorder, external wounds and so forth.

It is comprised of a main hinge assembly, an ankle assembly, a foot plate; a lower leg housing member; an upper leg housing member and supporting structure.

Fig. 1. 4 Knee Ankle Foot Orthosis

- HIP KNEE ANKLE FOOT ORTHOSIS (H. K. A. F. O)

HKAFO is basically a KAFO with addition of hip joint and pelvic section which provide control to selected hip motions. The motions included at the hip are front to back, side to side, and rotation. In the HKAFO there is a minimized risk of the hip moving out of proper position or dislocating. In this type of caliper, the hip and lower spine is stabilized in cases where the patient is weak or paralyzed.

Fig. 1. 5 Hip Knee Ankle Foot Orthosis

The average weight of stainless steel calipers are given below.

Table 1. 1 Weight of conventional stainless steel calipers

TYPE OF CALIPER

WEIGHT (kg)

A. F. O.

1. 100

K. A. F. O.

1. 600

H. K. A. F. O.

2. 250

2. LITREATURE SURVEY

Literatures on existing Calipers and design

In the literature survey, various designs of existing calipers have been proposed. The patient's comfort level, flexibility, cost-effectiveness and weight form the most important basis for the design of the caliper. Some of the recently published works are as follows:

Table 2. 1: Literature Survey

SL. NO

TITLE

AUTHOR

TECHNICAL DETAILS

CONCLUSIONS/

LIMITATIONS

1.

Anatomical Models of Diarthroidal Joints: Rigid Multibody Systems and Deformable Structures

JH Heggard

Computer Methods in Biomechanics and Biomedical Engineering- Volume 2, 2003

Mathematical methods to model diarthroidal joints. Modelling of the joints is necessary to be able to understand the difficulty faced in movement by a post-polio paralytic patient.

The various forces and stresses acting on the joints were studied in order to understand various basic movements and to help in the design of calipers.

2.

Bioengineering Analysis of Force Actions Transmitted by the Knee Joint

JK Marrisson

Biomedical Engineering, 5: 164-178, 1988

Determining forces acting on the knee joint as the caliper to be designed is a K. A. F. O(Knee-Ankle-Foot-Orthosis) caliper.

Forces on knee joint during locomotion

3.

Orthopaedic Prosthesis and Joint Implants

Shan Fengwang, Lichun L, Michael J. Yaszemski

Biomedical Engineering, 2: 1984

Study of Titanium and its properties such as biocompatibility, light weightedness, density, young's modulus to check for its use in the manufacture of calipers

Use of titanium in biomedical applications and how this could be extended to the manufacture of calipers and reduce the discomfort and weight of the same.

2. 1 WORKFLOW

Start

Caliper Classification

Similar Products Analysis

Commercial Intelligence

Material Selection

Manufacturing Process

Recognition of Tools and Machineries

Development

Design of Product

Modelling

Analysis

Fabrication of Prototype Model

Fabrication of Prototype Model

Testing

Verification I/P= O/P

Stop

Root cause analysis for failure

Recognition of Caliper and its Application

Fig. 2. 1 Workflow

3. SELECTON OF MATERIAL

For the design of a caliper, a material is chosen based on its physical properties such as tensile strength, elastic modulus, yield stress, etc. The choice of material is based on a comparative analysis of these factors. Ideally, a material should be chosen such that the caliper is:

Comfortable

Lightweight, yet strong

Easy to handle

Cost-effective

Durable

As attractive as possible

Easy to manufacture [8]

3. 1 MATERIALS CURRENTLY USED FOR PRODUCTION OF CALIPERS:

Braces are made from various types of materials-plastic, elastic, metal, or a combination of similar materials. At present calipers are of two types:

Metallic - made from Aluminum, Stainless steel

Non-metallic- made from polypropylene, reinforced carbon

Advantages of metallic calipers over non-metallic calipers:

Less expensive to manufacture: Metallic calipers are cheaper to produce because those manufactured using poly-propylene require specialized moulds to shape the polymer. The biggest expense in making plastic braces is the plaster bandage used for casting a mold of the leg.

Easier to customize for each patient: As the height and contours of each patient differs, the metal rods are easier to customize than plastic calipers.

They are quick and easy to make

They are more durable than plastic calipers.

If used with sandals or clogs, in hot weather they are cooler than plastic.

3. 2 TITANIUM AS AN ALTERNATIVE MATERIAL:

3. 2. 1 GENERAL PROPERTIES OF TITANIUM

Titanium is a chemical element, metallic in nature whose chemical symbol is Ti , atomic number 22 and atomic weight 47. 90. Ti is a transition metal silver in color It has the following properties:

low density

high tensile strength

corrosion-resistant

There are two allotropic forms and five naturally occurring isotopes of this element, 46Ti through 50Ti, with 48Ti being the most abundant (73. 8%). [8] It is the ninth-most abundant element in the Earth's crust (0. 63% by mass) and the seventh-most abundant metal. [8]

Titanium and its alloys possess suitable mechanical properties such as strength, bend strength and fatigue resistance to be used in load-bearing biomedical applications such as orthopaedics and dentistry.

Titanium is a reactive metal. In air, water, or arbitrary electrolytes an oxide layer is formed on the surface of the material. This oxide belongs to one of the most resistant compounds in the mineral world. As the oxide layer is a dense film it protects the metal from chemical attack which is of importance in an aggressive biological environment.

Within the human body, titanium is inert as the oxide layer which is formed is in contact with the biological tissue, is hardly soluble and in particular no ions are released that could react with other molecules. [9]

There are 22 grades of commercially available alloyed and unalloyed titanium. Based on the application, a suitable grade is chosen.

3. 2. 2 COMPARATIVE STUDY OF STAINLESS STEEL, ALUMINIUM AND TITANIUM

Metals used for the purpose of designing calipers are required to have both high static and cycle-dependent properties. Tensile yield and ultimate strength, modulus of elasticity, and fatigue endurance limit are the principal metallic strength attributes that must be determined. Wear resistance is also an important criterion for all biomaterials. Excessive wear can lead to premature mechanical failure of the replacement component.

Table 3. 1. Comparative study of the physical properties of the different materials

PHYSICAL PROPERTIES

MATERIALS

Stainless steel

Aluminium

Titanium

Density (g·cmâˆ’3)

9. 0

2. 70

4. 51

Ultimate strength (MPa)

860

455

900

Yield strength (MPa)

520

400

830

Yield stress (MPa)

210-350

40-50

240-370

Young's modulus (GPa)

205

70

110-125

Linear coefficient of thermal expansion (°F-1)

7. 8x10-6

12. 9x10-6.

5. 0x10-6

Density:

Density of a material is defined as the concentration of matter as measured by the mass per unit volume. A higher density indicates a higher mass for a particular volume.

Titanium has density between stainless steel and aluminium indicating that for the same volume of material, titanium is lighter than stainless steel but heavier than aluminium.

Ultimate strength:

Ultimate strength, also known as tensile strength, is defined as the maximum stress a material can withstand before necking. Ultimate strength should be

desirably, high for a material.

Titanium has ultimate strength higher than stainless steel and twice as high as aluminium indicating that it can withstand greater tensile stress i. e. it can withstand more stress before necking.

Fig. 3. 1 Stress-Strain curve

Yield Strength:

Yield strength is defined as the property of a material to resist deformation. For a good material, the yield strength should be high.

The yield strength for titanium is almost twice as high as stainless steel and aluminium indicating that it can withstand more stress without deforming permanently.

Yield Stress:

Yield stress is defined as the minimum amount of stress which when applied to the body causes permanent deformation. Even if the applied stress is removed at this point, the object does not return to its original dimensions.

The yield stress of titanium is almost equal to stainless steel but more than 6 times than that of aluminium.

Young's Modulus:

Young's modulus is the ratio between stress applied and resulting strain. It is used as a measure of change in linear dimensions upon application of tensile stress. If this ratio is large, it indicates that the material can withstand stress better with less deformation.

The Young's Modulus of titanium is higher than aluminium but lesser than that of stainless steel.

The modulus is an important concern in the orthopedic application of biomaterials because:

Bone has a modulus on the order of 17 GPa. The discrepancy between the modulus of bone and that of the alloys used to support structural loads means that the metallic devices implanted in the body take a disproportionate share of the load applied as stress.

According to Wolff's Law, bone adapts to applied stress. Because alloys cause stress shielding one result of the adaptation is that the bone associated with the implant does not become or remain as strong as it would in the absence of an implant. [12]

Linear Coefficient of Expansion:

Linear coefficient of expansion is defined as the increase in length per degree rise in temperature. If a metal is alternately subjected to heating and cooling cycles, it should maintain a certain tolerance of dimensions i. e. a low coefficient of thermal expansion is desirable.

The linear coefficient of expansion of titanium is much lesser than both stainless steel and aluminium indicating that the change in the dimensions of the object with change in temperature is less, which is desirable.

3. 2. 3 GRADES OF TITANIUM

There are 22 grades of commercially available alloyed and unalloyed titanium. [10]

Referenced standards: ASTM- American Standards for Testing Materials

This standard is issued under the fixed designation B 338 as revised on November

2003. [15]

ASTM Specification for commercially pure titanium: F-67

Table 3. 2 Grades of titanium

GRADE

COMPOSITION

Grade 1

Unalloyed titanium

Grade 2

Unalloyed titanium

Grade 3

Unalloyed titanium

Grade 7

Unalloyed titanium plus 0. 12 to 0. 25 % palladium

Grade 9

Titanium alloy (3 % aluminum, 2. 5 % vanadium)

Grade 11

Unalloyed titanium plus 0. 12 to 0. 25 % palladium

Grade 12

Titanium alloy (0. 3 % molybdenum, 0. 8 % nickel)

Grade 13

Titanium alloy (0. 5 % nickel, 0. 05 % ruthenium)

Grade 14

Titanium alloy (0. 5 % nickel, 0. 05 % ruthenium)

Grade 15

Titanium alloy (0. 5 % nickel, 0. 05 % ruthenium)

Grade 16

Unalloyed titanium plus 0. 04 to 0. 08 % palladium

Grade 17

Unalloyed titanium plus 0. 04 to 0. 08 % palladium

Grade 18

Titanium alloy (3 % aluminum, 2. 5 % vanadium) plus 0. 04 to 0. 08 % palladium

Grade 26

Unalloyed titanium plus 0. 08 to 0. 14 % ruthenium

Grade 27

Unalloyed titanium plus 0. 08 to 0. 14 % ruthenium

Grade 28

Titanium alloy (3 % aluminum, 2. 5 % vanadium) plus 0. 08 to 0. 14 % ruthenium

Grade 30

Titanium alloy (0. 3 % cobalt, 0. 05 % palladium)

Grade 31

Titanium alloy (0. 3 % cobalt, 0. 05 % palladium)

Grade 33

Titanium alloy (0. 4 % nickel, 0. 015 % palladium, 0. 025 % ruthenium, 0. 15 % chromium)

Grade 34

Titanium alloy (0. 4 % nickel, 0. 015 % palladium, 0. 025 % ruthenium, 0. 15 % chromium)

Grade 35

Titanium alloy (4. 5 % aluminum, 2 % molybdenum, 1. 6 % vanadium, 0. 5 % iron, 0. 3 % silicon)

Grade 36

Titanium alloy (45 % niobium)

From the comparative study, the following conclusions were drawn:

The yield stress, yield strength and ultimate strength are much higher for titanium. Hence it serves as a suitable material for calipers as it has to withstand the stress applied by the body weight and external forces.

Lower stiffness of titanium with respect to stainless steel reduces the severity of stress-shielding.

The density of titanium is lesser than stainless steel; therefore the calipers would be much lighter than those made of stainless steel, almost by half.

As linear coefficient of thermal expansion is lesser for titanium, the caliper dimensions would not change much with change in temperature.

Titanium is more corrosion resistant than stainless steel. Stainless steel relies on chromium to render it passive to corrosion. Titanium however develops passivity on its own from the stable oxide film that forms on its surface.

Unalloyed titanium grade 2 has higher ductility and is hence, cast, formed, joined, and machined with relative ease as compared to the alloyed grades.

4. DESIGN OF CALIPER

4. 1 DESIGN OF EXISTING CALIPERS

4. 2 DEVELOPMENT OF IMPROVED DESIGN

Software that was used for the development of caliper design: Autodesk Inventor Professional 2009.

4. 2. 1 ABOUT AUTODESK INVENTOR PROFESSIONAL 2009

Autodesk Inventor Professional 2009 helps you design, visualize and stimulate the end product desired digitally. It not only includes the 3D mechanical design and CAD productivity, but also the essential tooling of various parts of the end product required such as plastic, that lends itself to manufacturing, and also facilitating in validation of the product digitally, sparing the need to test with physical prototypes.

With the integration of motion simulation and stress analysis tools in Autodesk Inventor Professional 2009, marketing a product becomes a much easier. Effective prediction on how the product will work in real-time conditions can be done and also automation of important aspects of the design such as the injection molds for plastic parts help greatly in minimizing errors to a good extent.

An intuitive design environment of Autodesk Inventor Professional 2009 helps in the development of initial sketches and models of different parts. Also, this software helps by automating the basic geometrical sketches to actual prototypes making using of materials such as plastic, steel frames, tubes etc. This therefore reduces the geometry burden and the time required to make necessary changes and bring about innovation in the product, thereby reducing the time it takes to reach the market.

Validation, in earlier times, was a very time consuming and expensive process involving skilled specialists but Autodesk Inventor Professional 2009 has made the entire process very simple and simulation expertise is not required now. Simulation and optimization of designs digitally has become very easy due to this software. Simple user interface helps in part by part design and integration. Stress analysis can also be performed to evaluate areas of stress concentration and hence helps in distribution of the same by slight design modifications.

Improved Design:

Auto Desk Inventor 2009 supports all major drawing formats like DWG and some of the improved features compared to its previous versions include:

Design views in high speed - Saves a lot of time. Viewing of drawings and annotation takes very less time when compared to the previous versions.

Betterment in error handling - High level of intelligence to give suggestions regarding geometrical issues.

Faster startup time - Launch time is much faster when compared to previous versions.

Part by part design view - Immediate definition and change in any part including dimensions and coloring and suitable assembly instantly.

New Standards for 3D Modeling Ease of Use

Autodesk Inventor 2009 helps focusing on the problem rather than trying to gain expertise over using the software as such, owing to its advanced user interface and features, making complex dialog boxes redundant.

Inventor Fusion - Simple tools to explore new shapes and easy on the spot modification of model from any source.

Improved design feature creation - Better control over the geometry of the design with productivity uncompromised.

Assembly design features [20]

Assembly Snap tool

Interference analysis and contact detection

Assembly configurations

Large assembly performance

Frame Generator

Weldments

Content Center

Design Doctor

Direct manipulation

It is an important feature of Autodesk Inventor Professional 2009 which helps in uninterrupted design workflow. Being able to control all the commands exactly at the point needed gives more room for free sketching, quicker assembly and better accuracy.

Sustainable Design

Material selection can now be done considering environmental effects and cost effectiveness. Using Autodesk, it is now possible to access environmental information on materials required for fabrication and make prudent decisions based on careful analysis.

4. 2. 2 ENGINEERING DRAWINGS OF THE CALIPER

During the modeling, different parameters were measured which included

Diameter of the mid- thigh

Diameter of distal end of the thigh

Distance between mid- thigh and distal end of the thigh

Diameter of proximal end of the calf

Distance between distal end of the thigh and proximal end of the calf

Diameter of the distal end of the calf

Distance between proximal and distal end of the calf

Diameter of ankle

Length of the foot

Breadth of the toes

Breadth of mid-foot

Based on these parameters, the design of the calipers was developed using Autodesk Professional Inventor 2009

The drawing was modeled in parts and later assembled into the complete caliper as shown in the drawings.

All dimensions are in mm

Fig 4. 1 Engineering drawing of KAFO

All dimensions are in mm

Fig 4. 2 Engineering drawing of upper leg supporting structure (thigh)

All dimensions are in mmFig 4. 3 Engineering drawing of lower leg supporting structure (Calf)

All dimensions are in mm

Fig. 4. 4 Engineering drawing of the ankle and foot supporting structure

All dimensions are in mm

Fig 4. 5 Engineering drawing of Ti-Strip1

All dimensions are in mm

Fig 4. 6 Engineering drawing of Ti-Strip 2

All dimensions are in mm Fig 4. 7 Engineering drawing of Ti-Bend Strip

Fig 4. 8 Engineering drawing of the Male Clamp

Fig 4. 9 Engineering Drawing of Female Clamp

Hence, by using Autodesk Inventor Professional 2009, the design for a caliper was developed.

The different parts of the caliper were developed individually and later assembled to form a complete model. These diagrams are used as a basis for the development of the prototype.

The major changes that were incorporated in the design were at the knee joint:

Male and Female Clamp were used to replicate the hinge joint at the knee.

In order to assist in easy bending of the caliper while sitting, a rivet was introduced which when unscrewed, will faclitate flexion at the knee.

This is primarily useful while sitting and travelling as the caliper need not be completely removed.

5. DEVELOPMENT OF PROTOTYPE

The development of prototype was conducted in essentially three steps:

Development of PVC prototype

Identification of problems and corresponding corrections made

Development of titanium protoype

5. 1 MANUFACTURING PROCESS

There are five major steps in manufacturing the Polyvinylchloride prototype. They have been listed and enumerated below:

Marking

This is the foremost step in manufacturing. It is also known as 'Material Planning'. Knowing the required dimensions is a prerequisite. Once the dimensions for every part of