BIONICS: TENDON LOCKING MECHANISM

INDUSTRIAL DESIGN
SPECIAL PROJECT

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Guide: Prof. **V. P. Bapat**

Submitted in the partial fulfillment of the requirements of the degree of
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BIONICS: TENDON LOCKING MECHANISM

By
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Guide…………………………………………………………………………………

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With a sense of achievement , satisfaction and deep sense of gratitude I would like to thank my guide ***Prof. Vijay P. Bapat*** who encouraged and inspired me in taking up this project and whose help and support has been instrumental in the completion of this project.

I would also like to thank my family members for their patience and support in whatever I have done till date.

I thank my department Industrial Design Centre for providing me with wonderful facilities during the course of my project development.

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CONTENTS

Introduction

Nature has played an important role in the evolution of human beings. It has more or less been the crux of the inspiration for the various inventions of man since the very early ages.

Biology has had to solve engineering and other common problems since the appearance of life on earth. Design and function in plants and animals have been optimized under evolutionary pressures over millions of years, a small step at a time. These long lead times do not fit easily with the more frenetic pace of the engineering world of today but to dismiss on these grounds the solutions that nature has arrived at would be foolish and arrogant. Therefore, it is not surprising that mankind has always admired biological structures and often been inspired by them, for we can appreciate their esthetical attributes as well as their engineering and design content. Some early examples of engineering structures which borrowed ideas from nature include the Eiffel Tower, Crystal Palace and all manner of primitive and rather ineffectual flying machines.

The word "bionic" was coined by Jack E. Steele in 1958, possibly originating from the Greek word "βίον", pronounced "bion", meaning "unit of life" and the suffix -ic, meaning "like" or "in the manner of", hence "like life".

The transfer of technology between life forms and synthetic constructs is, according to proponents of bionic technology, desirable because evolutionary pressure typically forces living organisms, including fauna and flora, to become highly optimized and efficient. Bionics is the application of natural methods and systems to the study and design of engineering systems and modern technology.

Bionics is the study of how humans and animals perform certain tasks and solve certain problems, and of the application of the findings to the design of electronic devices and mechanical parts. It is also known as biomimetics, biognosis, biomimicry, or bionical creativity engineering. Biomimetics is a modem word first used at a workshop in 1991 organised by the US Air Force Office of Scientific Research.

The word biomimicry aptly showcases the actually meaning of bionics. Bionics basically means mimicking nature and adapting it to solve day-to-day problems. To abstract ideas from biology and turn them into practical engineering solutions, all disciplines have something to contribute. Success can only comes from their integrations.

Applications of Bionics

The applications of bionics to the field of science and technology have been vast but still there is only 10 percent overlap between technology and biology according to Julian Vincent, professor of biomimetics at the University of Bath in the UK.

In the field of computer science, the study of bionics has produced artificial neurons, artificial neural networks, and swarm intelligence. Evolutionary computation was also motivated by bionics ideas but it took the idea further by simulating evolution in silico and producing well-optimized solutions that had never appeared in nature.

Some of the famous examples of application of bionics to design are as follows:

- Velcro is the most famous example of biomimetics. In 1948, the Swiss engineer George de Mestral was cleaning his dog of burrs picked up on a walk when he realized how the hooks of the burrs clung to the fur.
- Cat's eye reflectors were invented by Percy Shaw in 1935 after studying the mechanism of cat eyes. He had found that cats had a system of reflecting cells, known as tapetum lucidum, which was capable of reflecting the tiniest bit of light.
- Leonardo da Vinci's flying machines and ships are early examples of drawing from nature in engineering.

- Julian Vincent drew from the study of pinecones when he developed in 2004 "smart" clothing that adapts to changing temperatures. "I wanted a nonliving system which would respond to changes in moisture by changing shape", he said. "There are several such systems in plants, but most are very small — the pinecone is the largest and therefore the easiest to work on". Pinecones respond to higher humidity by opening their scales (to disperse their seeds). The "smart" fabric does the same thing, opening up when the wearer is warm and sweating, and shutting tight when cold.
- "Morphing aircraft wings" that change shape according to the speed and duration of flight were designed in 2004 by biomimetic scientists from Penn State University. The morphing wings were inspired by different bird species that have differently shaped wings according to the speed at which they fly. In order to change the shape and underlying structure of the aircraft wings, the researchers needed to make the overlying skin also be able to change, which their design does by covering the wings with fish-inspired scales that could slide over each other. In some respects this is a refinement of the swing-wing design.
- Some paints and roof tiles have been engineered to be self-cleaning by copying the mechanism from the Nelumbo lotus.

- Nanostructures and physical mechanisms that produce the shining color of butterfly wings were reproduced in silico by Greg Parker, professor of Electronics and Computer Science at the University of Southampton and research student Luca Plattner in the field of photonics, which is electronics using photons as the information carrier instead of electrons.
- The wing structure of the blue morpho butterfly was studied and the way it reflects light was mimicked to create an RFID tag that can be read through water and on metal.
- Neuromorphic chips, silicon retinae or cochleae, has wiring that is modeled after real neural networks. S.a.: connectivity
- Synthetic or "robotic" vegetation, which aids in conservation and restoration, are machines designed to mimic many of the functions of living vegetation.
- Medical adhesives involving glue and tiny nano-hairs are being developed based on the physical structures found in the feet of geckos.

Thus the reach of bionics is in all the fields mechanical desing, materials, medical applications, locomotion, etc

Aim of Project

To study the Tendon Locking Mechanism (TLM) in bat for its application in day to day life based on bionic principles.

The proposed project aims at understanding the capabilities of bionic principles to solving engineering & day-to-day problems and studying the bats griping mechanism and converting it into a useful application.

Methodology

To understand it one has to understand the principle of levers and kinematic chains. In technical words these are the physical material elements, which actually transfer force from source to application with predetermined ratio, but in biological world it is done with bones and muscles.

The methodology followed is:

- Studying and understanding the arrangement of muscles and their mechanisms
- Converting the biological mechanism into a kinematic chain.
- Analysing the mechanism based on its kinematics for use in various applications.
- Choosing a specific application and applying the TLM.
- Generating a working model based on the TLM principle

Bat

Bats have some very unique abilities viz., ultrasound vision, large wings that can fold and be very compact, hanging upside down for very long time ,etc.

The ability of a bat to hang upside down for prolonged periods was considered.

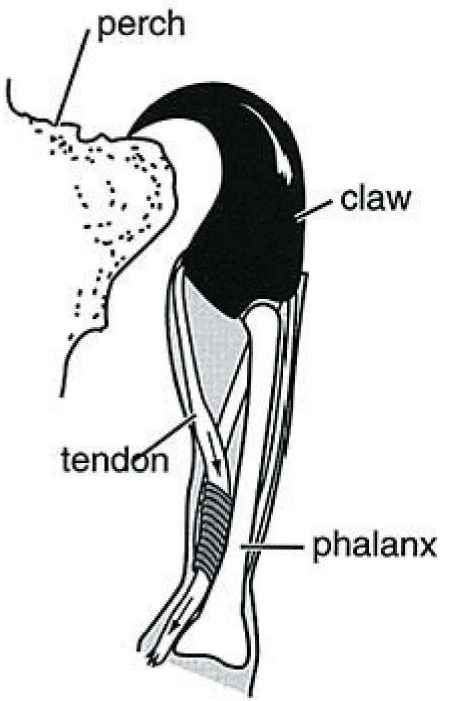
All species of bats exhibit morphological specialization similar to those

in the avian foot, and referred as Tendon Locking Mechanism (TLM).

Locking mechanisms are found in all the digits of the hind limb and in

the thumb of bat forelimb.

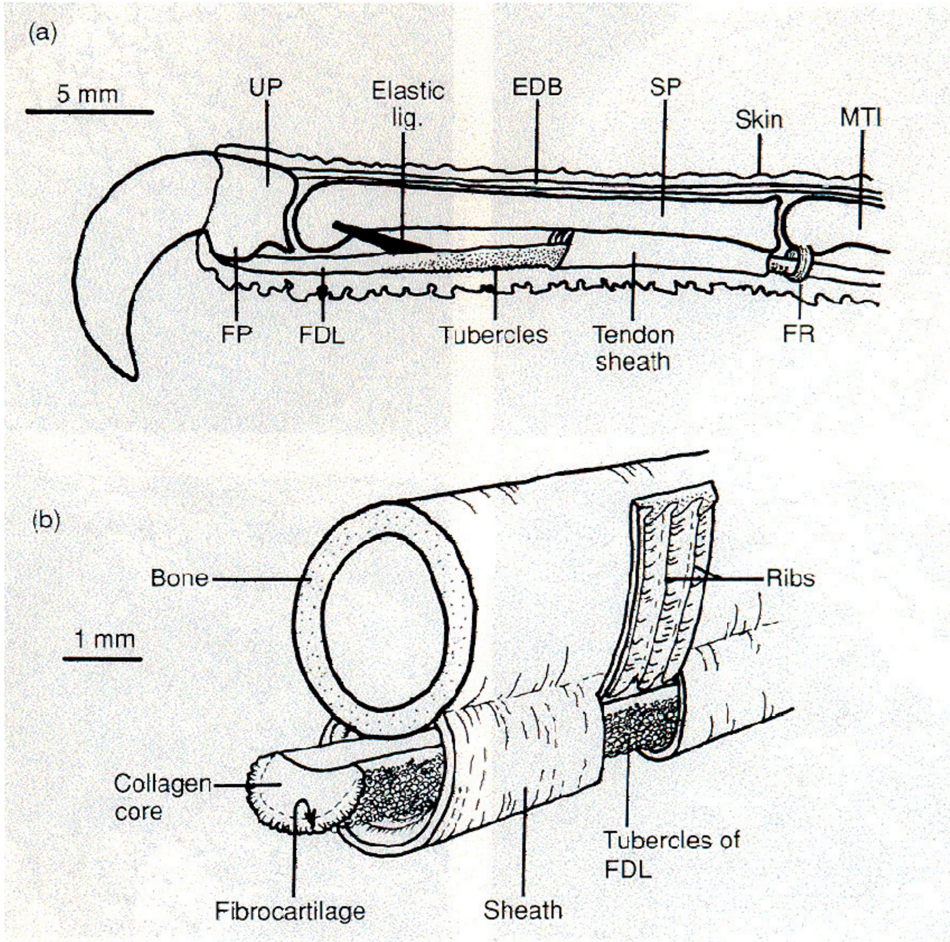
Tendon Locking Mechanism [TLM]



Bats have a unique biomechanical arrangement in their body that enables them to hang upside down for very long durations. This is basically due to the tendon locking mechanism.

Nearly all bats rest and sleep, or roost, hanging upside down by their hind feet. Bats do not need to expend energy to maintain this position as they hang; its own weight causes the foot tendons to automatically grasp, firmly holding the animal in place. Almost all bats have Tendon Locking Mechanism on their toes, which permit long-term hanging without constant contraction of flexor muscles.

During hanging, bats use their hind limb digits to suspend themselves in head-down position. Hence they have very thin hind limb bones. The bones cannot tolerate compression. Since the compressive load associated with an upright body stance are likely to cause buckling in delicate bones, hanging in which tensile loads are applied to the hind limb, make these bones less prone to mechanical failure.



In the Fig.
UP - Ungual Phalanx
FP - Flexor Process
FDL - Tendon of M. FDL
EDB - Tendon of M. extensor digitorum brevis
SP - subterminal Phalanx
FR - Flexor retinaculum
MT1 - Metatarsal 1

Initially the FP is rotated due to force applied by SP and MT1 respectively. Due to this movement tendon sheath, ribs and tubercles of FDL gets interlocked.

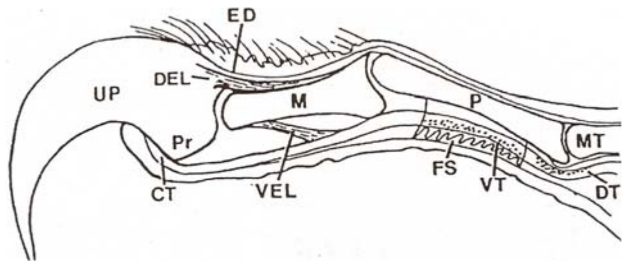
This mechanism is clearly described in the next with figures.

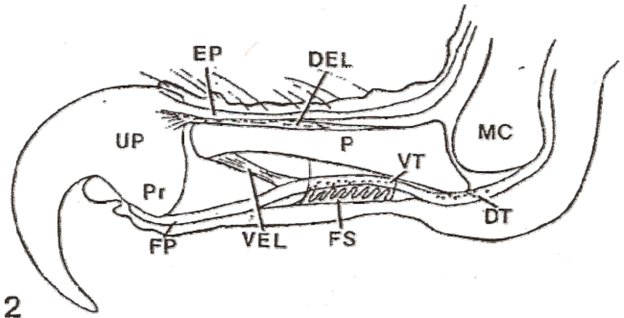
Bats have tendinous arrangement in the hind limbs, which acts as an automatic digital flexor mechanism (Borelli, 1680; Watson, 1869; Bock, 1965; King and McLelland, 1984). A mechanism by which the tendons of the deep digital flexor muscles (M. flexor digitorum longus and M. flexor hallucis longus) are able to lock the digits in a flexed position has been described. Locking of digits is achieved by virtue of rough patches on the plantar surfaces of the tendons engaging with corrugation of the flexor tendon sheath.

Upon the contact of the hind leg claws with the substrate, contraction of the digital muscle pulls the distal portion of the flexor tendons proximally, through a series of tendon sheath, which contains thickened section called retinacula. When the roughened sections of tendon are positioned beneath the corrugated retinacula, there is engagement between the scales of tubercles on the tendon surface and the transversely arranged, rib-like plicae that invest the inner walls of the retinaculum. In theory, digital flexion is maintained without continued contractile activity of the digital flexor muscles, and the energetic cost of hanging is lowered.

Hind limb:

Skeletal component is same as those of human hind limb, with the exception of an additional bony element - the calcar. This is functionally part of the uropatagium, or tail wing. The fibula (outer bone) articulates with the tibia (inner bone) distally. In the normal (hanging) position the foot is highly plantar flexed, with the metatarsals (bone between ankle and the toes) approximately parallel to the longitudinal axis of the tibia. Digit I (hallux) is slightly shorter than digits II - IV, which do not differ greatly in length. All digit flex in sagittal plane. Lateral rotation of the hind limbs by 180^0 at the hip jo;nt results in the backward facing knee. This arrangement helps in taking off and landing.





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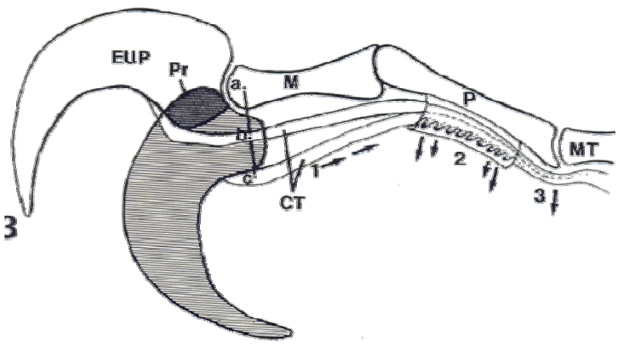


3

Locking mechanism tendon be compressed between bone and structure. The tendon must be initially pulled around the flexor. As the digits curl, the motion carries the line of

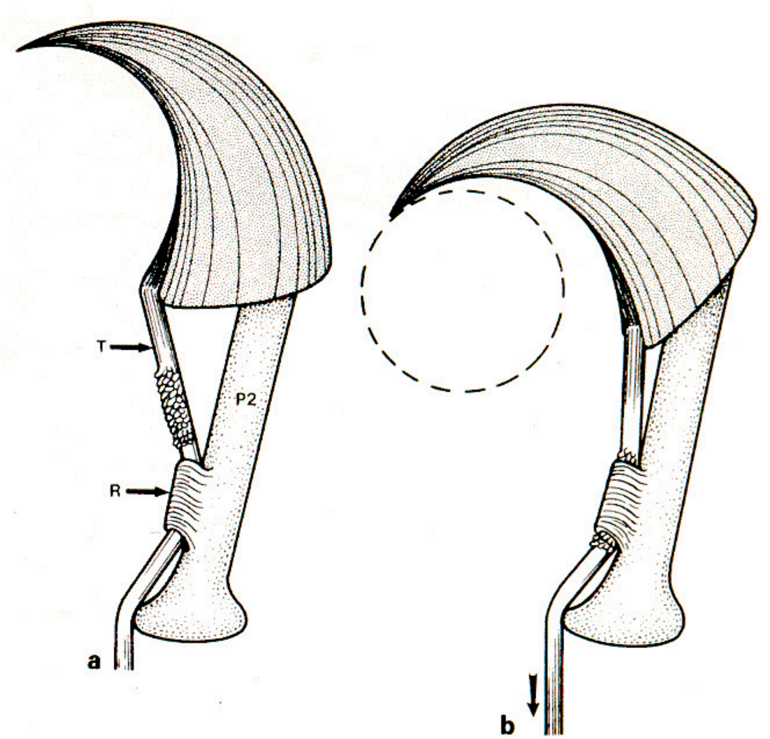
The locking of two main components of the TLM in hanging posture occurs in two ways.

The digits are curled around a support then it is possible that the tendon sheath and the tendon be compressed between bone and structure. The tendon must be initially pulled around the flexor. As the digits curl, the motion carries the line of action of the flexor tendon farther away from the axis of rotation of the distal phalanx joint. The moment arm is therefore increase with the simultaneous increase in torque at the distal phalanx joint. Since a force will produce a greater torque when moment arm is large, it appears that flexion of the distal phalanx joint is powerful in bats. The grip established on the substrate by this forceful initial flexion of the ungula phalanx is maintained by locking the tendon in place with TLM.

Only point of contact with the support is made by the distal phalanx, the tendon will be forced against the restraining tendon sheath. This occurs, as there is a component of force acting perpendicular to the long axis of tendon. Thus the line of action of tendon is changed and the components of TLM are engaged.

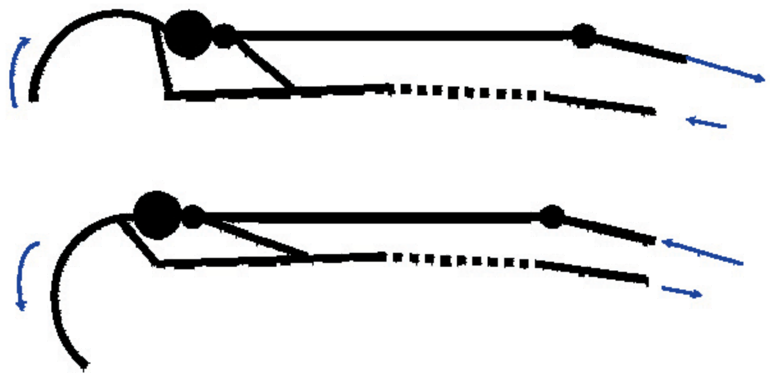
Unlocking mechanism

The actual method of unlocking of tendon has not been determined so far. But it is probable that relaxation of two muscles (FDF and FDT), coupled with the effect of gravity and contraction of EDB is sufficient to bring to extend the digit. Once the tendon disengages from the tunnel ridges it will be pulled distally and towards the phalangeal bone (i.e. away from ridges) by action of flexor elastic ligaments.



Summarised working of TLM

From this study of bats, it has been found that bat uses their hind limb digit to hang upside down while roosting or sleeping without spending energy. It even remains in hanging position after its death. The mechanism found in their hind limb for hanging is Tendon Locking Mechanism (TLM). Each digits of bats hind limb have tendons, which are able to lock the digit in flexed position. The sub terminal phalanx (a bone of the toes) has tendon sheath, which has corrugated rib like plicae on the inner walls. The tendon and tendon sheath are the main components of the TLM. The tendons have rough patches on their plantar surface, which engages with corrugation of tendon sheath and thus locking is achieved. For unlocking the tendon disengages as the muscle extends due to effect of gravity and contraction of EDB (another tendon). The tendons are then pulled back to their original position by action of elastic ligaments.



Kinematic Linkage Diagram

Advantages:

- Zero energy consumption
- Only tensile loading
- Easy locking & unlocking

Possible applications:

- Gripper pliers
- Door lock handle
- Handle for kitchen utensils
- Robotic arms for assembly lines
- Bench vice

and quick release applications.

Bench vice was selected as the device to redesign using bats TLM.

Bench Vice

Bench vice is one of the most common and most frequently used device in a workshop. It is used to hold a job firmly between its two jaws.

Operating Procedure:

The gap between the two jaws of the bench vice is varied by rotating the turn handle which is connected to a lead screw. This handle is used to tighten and loosen the grip over the job.

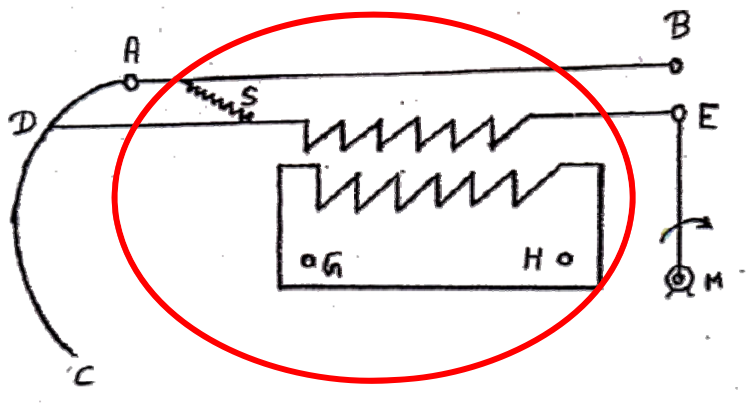
Lacunae Identified:

- Mounting of a job in the jaws is time consuming as the lead screw has to be rotated using the handle.
- When working with jobs of same size the pressure applied on the job while mounting cannot be maintained constant.
- Being made of cast iron, a bench vice is not material efficient.

Tendon locking mechanism can help solve these problems as the mechanism is primarily a 2D linkage and has capability for quick release.

Design Brief

"To design a bench vice that will aid quick clamping and quick release of the jobs to be worked upon and also be material efficient ".



Analysis & Design

Considering the Bat's TLM and the components of a bench vice following variables are available for design:

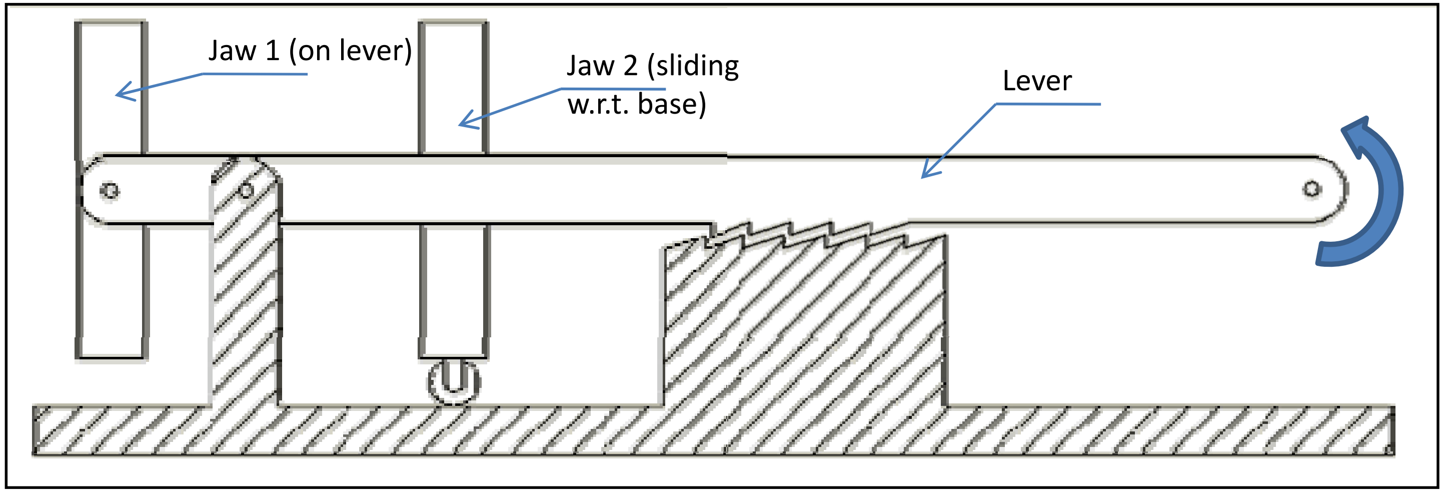
- Link geometry.
- Placement of spring.
- Adjustability using teeth mechanism or screw mechanism or their combination.
- Teeth profile, pitch, no. of teeth required for locking.
- Controls for clamping and release.

Of the entire bat mechanism following part of the geometry was initially identified and worked upon to convert into a bench vice.

Components: The spring(S) and the teethed locking elements

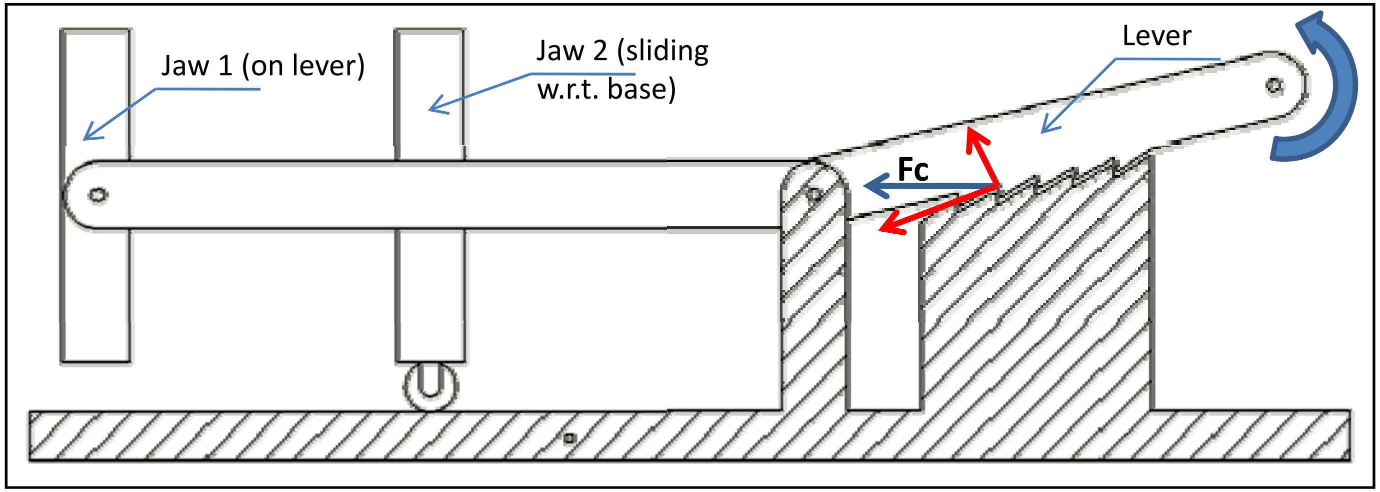
Based on this, various configurations were tried in 2D and following were the few configurations made.

Configuration 1:



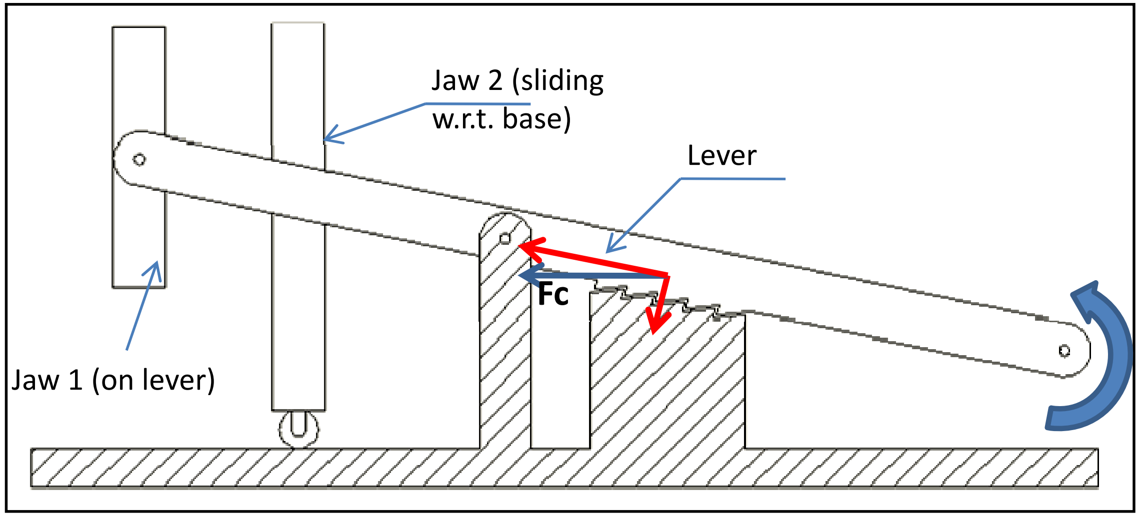
- The basic components of bench vice are the two jaws, of which one moves and allows for clamping the job. Here the 1st jaw is pivoted to the lever and the 2nd jaw slides along the base. The lever has to be pushed up to release the job.
- Though this setup achieved quick clamping and release, adjusting the jaws to the required size was a problem as it was required to slide the 2nd jaw every time the dimension of job to be mounted changed.
- Also the job had to be mounted right at center of the jaws, else the pivot of 1st jaw would not allow for clamping of the job.

Configuration 2:



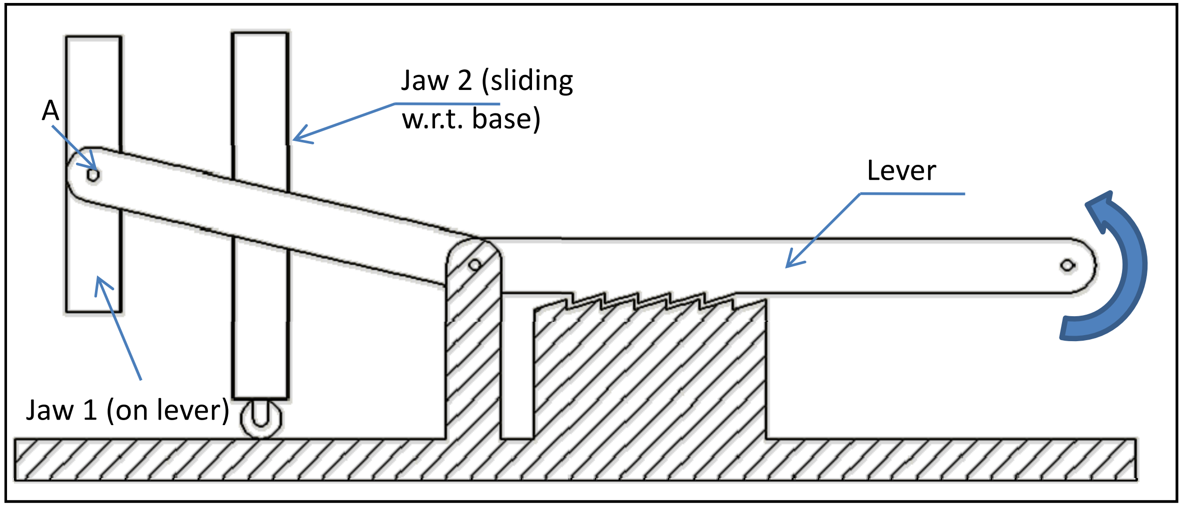
- Here the 1st jaw is mounted on the lever itself and the 2nd jaw slides along the base. To release the job the lever is pushed up from the right end and hence the jaw 1 moves down & along an arc releasing the job.
- The job has to be positioned between the top half of the jaw for release & clamping. Thus the jaw 1 is used only for clamping and releasing.
- The angled arm of the lever at the teeth locking end allowed for easy removal of job as the component of clamping force (**Fc**) has a component in the releasing direction, but this also means there could be chances of slipping when heavy working force is applied on the job.

Configuration 3:



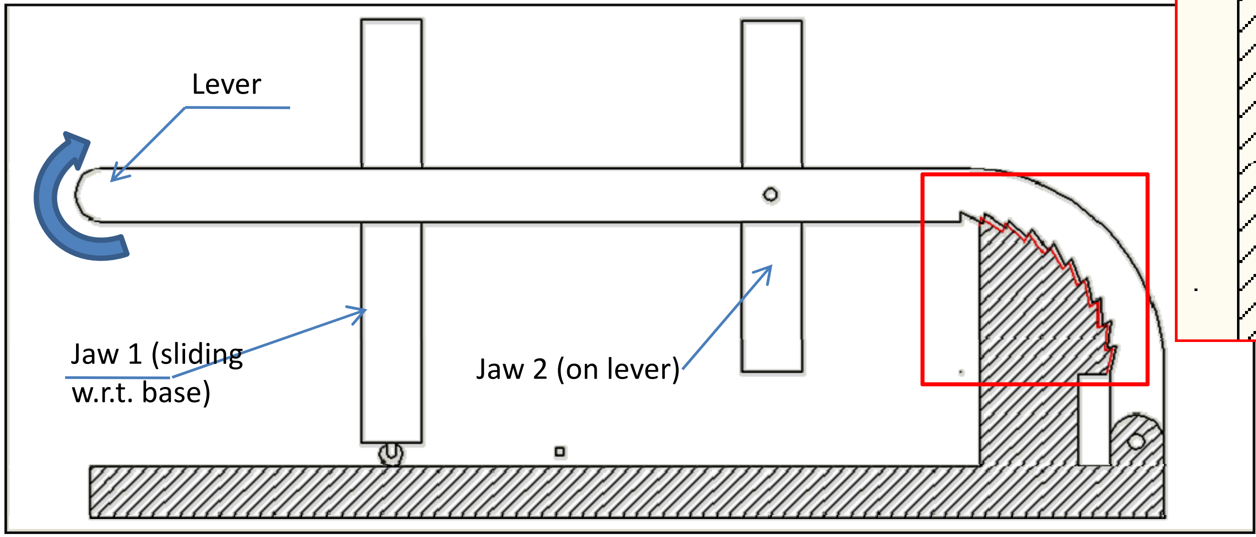
- Here the 1st jaw is mounted on the lever itself and the 2nd jaw slides along the base. To release the job the lever is pushed up from the right end and hence the jaw 1 moves down & along an arc releasing the job.
- As the angle of the lever is in downward direction towards right good locking of the lever with the teeth is achieved as the component of clamping force (**Fc**) has a component in the direction opposite to that of releasing. But this also means increase in wear and tear due to releasing action.

Configuration 4:

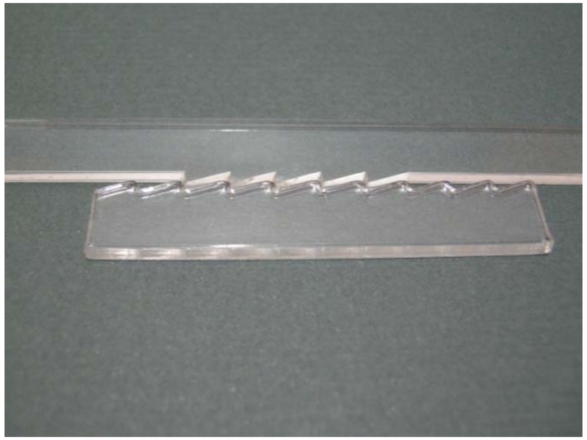


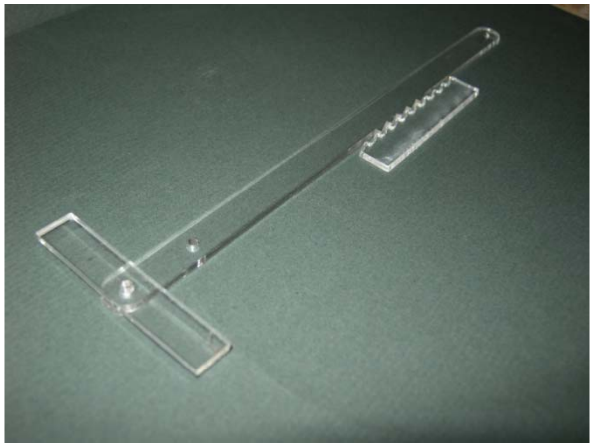
- Here the 1st jaw is mounted on the lever itself and the 2nd jaw slides along the base. To release the job the lever is pushed up from the right end and hence the jaw 1 moves down & along an arc releasing the job.
- Here the angled left end of the lever and 1st jaw with smaller height below the mounting point (A) allows for compact size (along the vertical direction).

Configuration 5:



- Here the 1st jaw slides along the base and the 2nd jaw is mounted on the lever itself e. To release the job the lever is pushed up from the left end and hence the jaw 2 moves down & along an arc releasing the job.
- Here the curved locking teeth profile creates a problem while engaging and disengaging as the teeth cut along the line of motion (see the inset fig.)

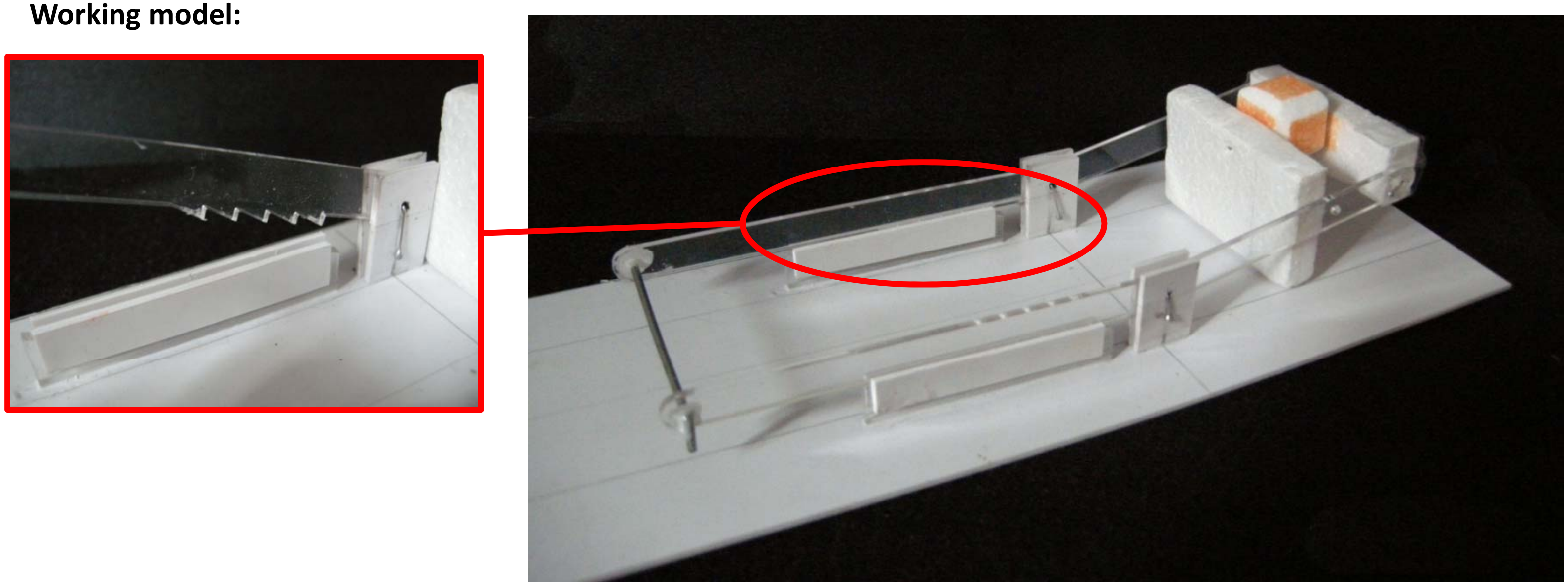




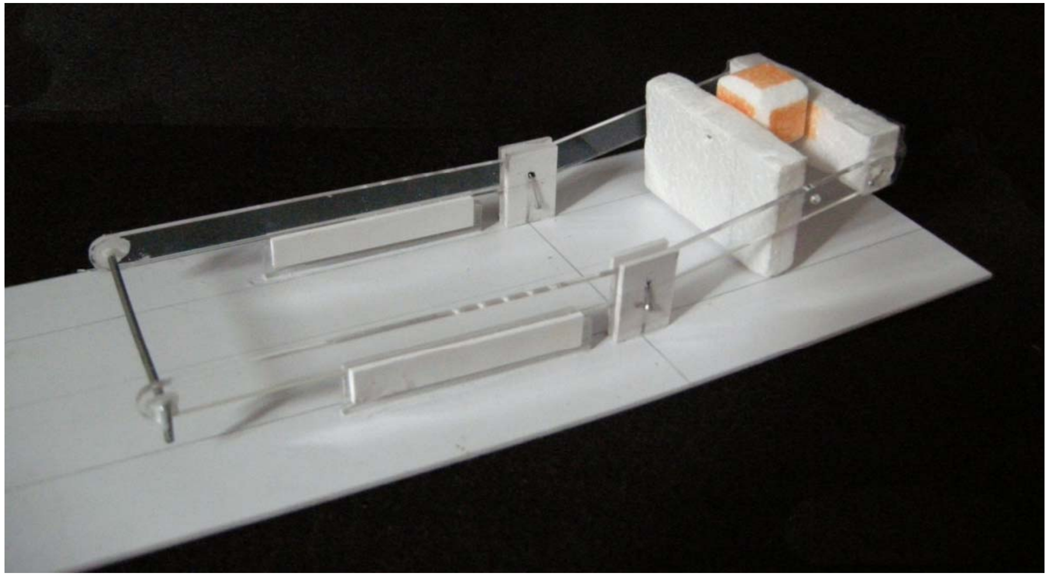
To analyse these 2D ideas mock up linkages were made and worked upon for locking at various angles. These linkages were then checked for their working in 2D for various aspects like locking & adjustability.

Each of these were then used to mount in 3D and check for functionality.

Working model:

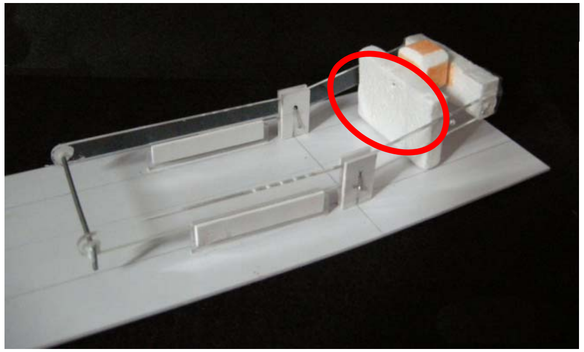


Of all the configurations tried in 3D the configuration no. 4 seemed to work. Hence a proper working exploratory model was made as shown. Here the 1st jaw mounted on the lever clamps the job when the lever is locked into the teeth shown. This is due to the angled portion of the lever on which the jaw is mounted, which when rotated up around the pivot moves along a arc and grips the job. The adjustment is achieved using the 2nd jaw controlled by lead screw.



Features:

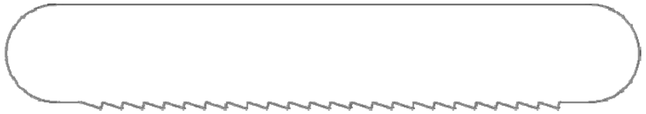
- Quick clamp & quick release.
- Light weight.
- Material efficient (low material usage)

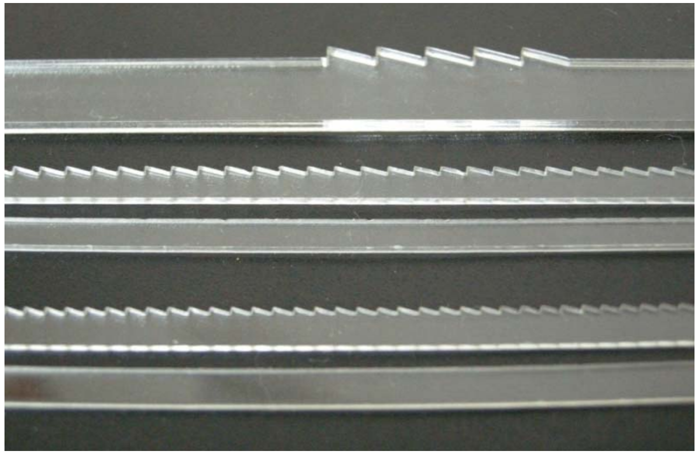


Initial Observations:

- The mechanism makes quick clamping and release available every time. Whenever the dimension of the job changes the 2^{nd} jaw has to be adjusted using the lead screw that drives the 2^{nd} jaw but quick release is always available.
- The width of the job piece that can be mounted is restricted by the jaw width which in turn is restricted by the two links on each side.
- The adjustments for clamping & release and the sliding of the jaw are available on the farther side of the jaws making operating the vice difficult for the user due to larger distance

Refinements

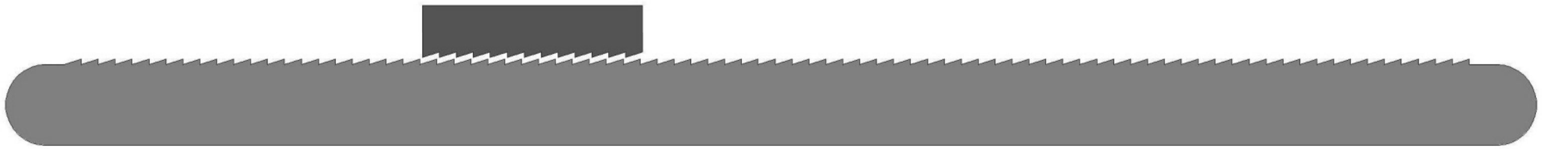


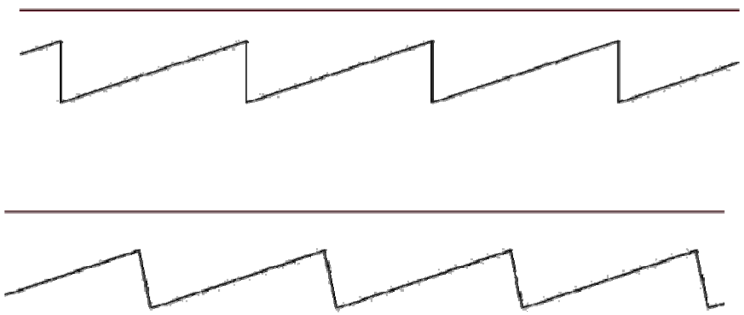


To solve the lacunae in new the design, decision was made to have complete adjustability using the clamping teeth of the mechanism. This would give quick clamping and quick release even with jobs of varying dimensions.

For this the entire guides for the jaws needed to be in form of tracks having teeth all along its length.

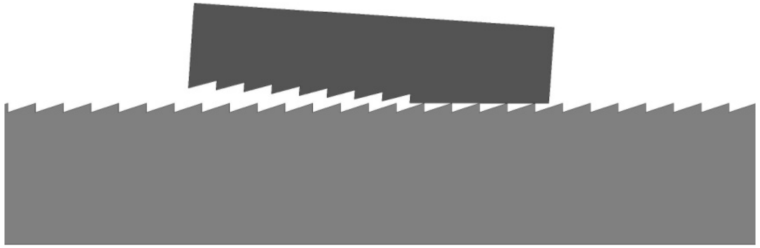
To achieve fine adjustments using these track mounted jaws, the teeth had to be of as small a pitch as possible. Hence tracks of varying teeth sizes were made to check the minimum possible teeth pitch that could give positive locking.

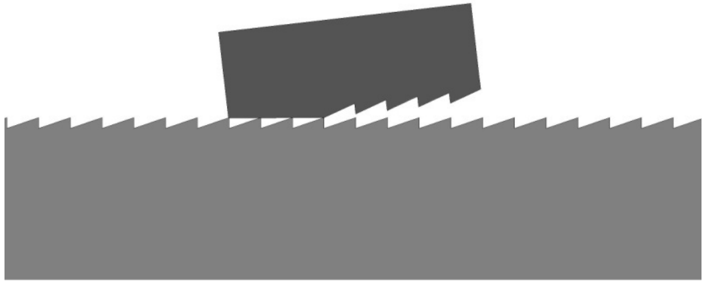




This meant having the jaws mounted on a slider that would slide along the tracks. With the specific profile of the teeth the slider would slip in one direction only, to have it moving in both the directions new teeth profile was tried which would have lesser locking and would be held in contact with the track using a spring. But this seemed risky as chances of slip with failure of spring were high.

Hence, there was a need for a mechanism that would detach the slider on which the jaw is mounted temporarily while adjusting the jaws. This would require a cam like mechanism that will push the slider away from the track.



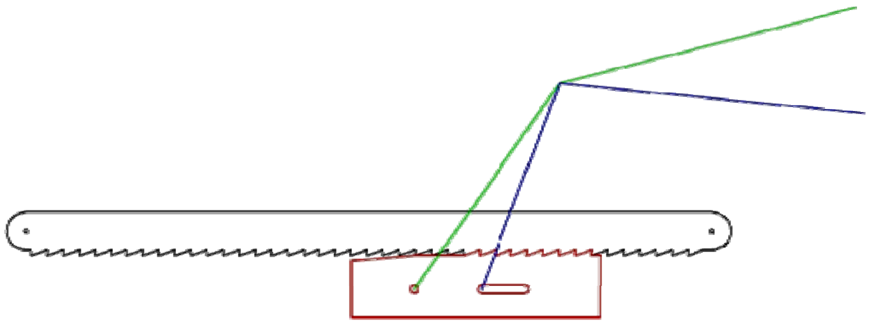


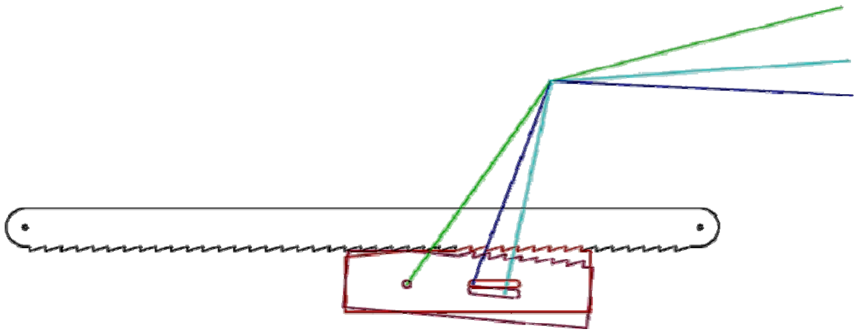
While exploring the sliding mechanism it was realised that a slight taper in the direction of the teeth taper would aid sliding when the slider is lifted from one end as shown in adjoining figure.

A taper in opposite direction would jam the slider with track with wear of the lifting mechanism. Hence the first option was selected for final concept refinement.

From this it was clear that the slider needed to be rotated abut a pivot for releasing it off the track. This could be achieved using a certain lever arrangement.

Also it was clear that a simple taper doesn’t allow the slider to lock with the track hence a new slider was made as shown.



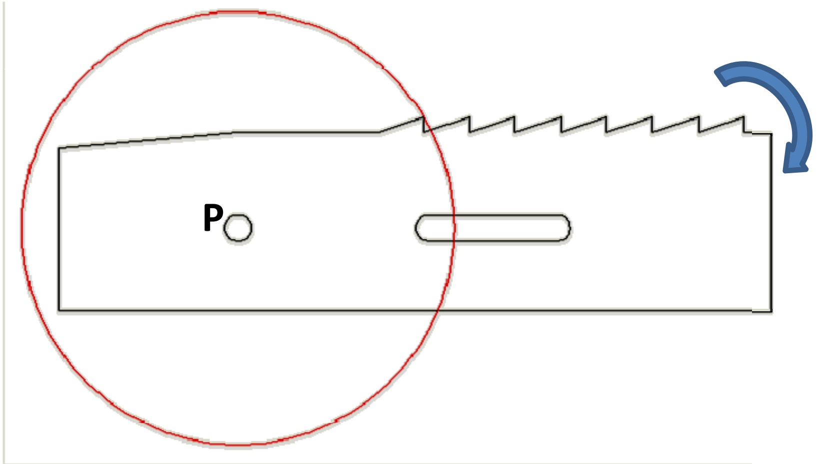


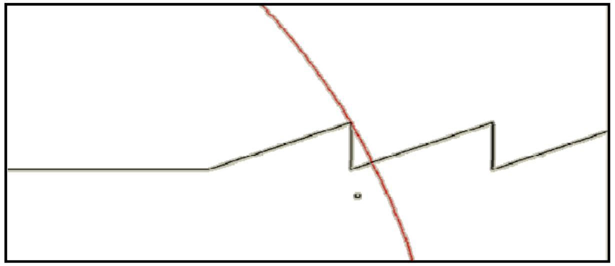
Following mechanism was selected to achieve the desired rotation of the slider.

When the blue lever is pulled towards the green lever it pushes the slider away from the track and rotates it about the pivot on the green lever. The jaw is mounted on the green lever and slides parallel to the tracks on guide rails.

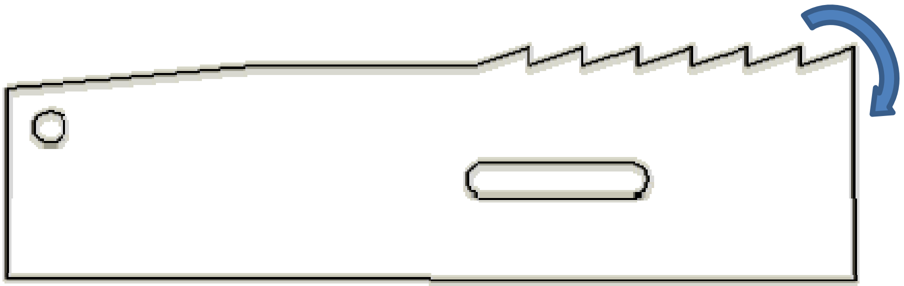
This adjustability is decided by the pitch of the teeth which is completely unacceptable as it cannot clamp jobs of any dimension. To provide for clamping of jobs of all sizes the second jaw is controlled by a lead screw for fine adjustments.

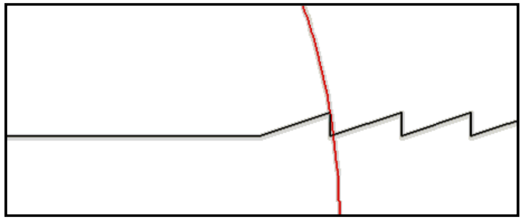
Also the pitch of the teeth need not be very small as the adjustment is available with the 2nd jaw.

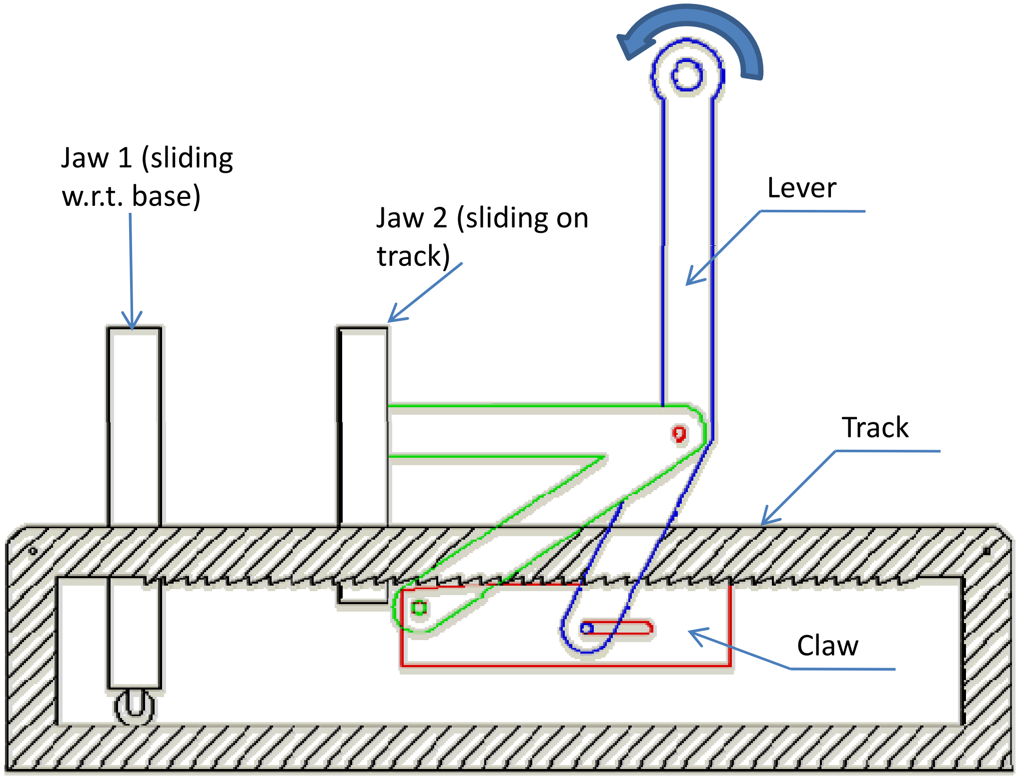




While unlocking the above link is rotated about the pivot (P), the teeth also pivots and move along a circle (shown in red for 1st teeth). Along the circular path the teeth causing an undercut. Hence the pivot for this element was shifted upwards (refer fig. below) as a result the undercut reduced from 0.7 mm to 0.2 mm.

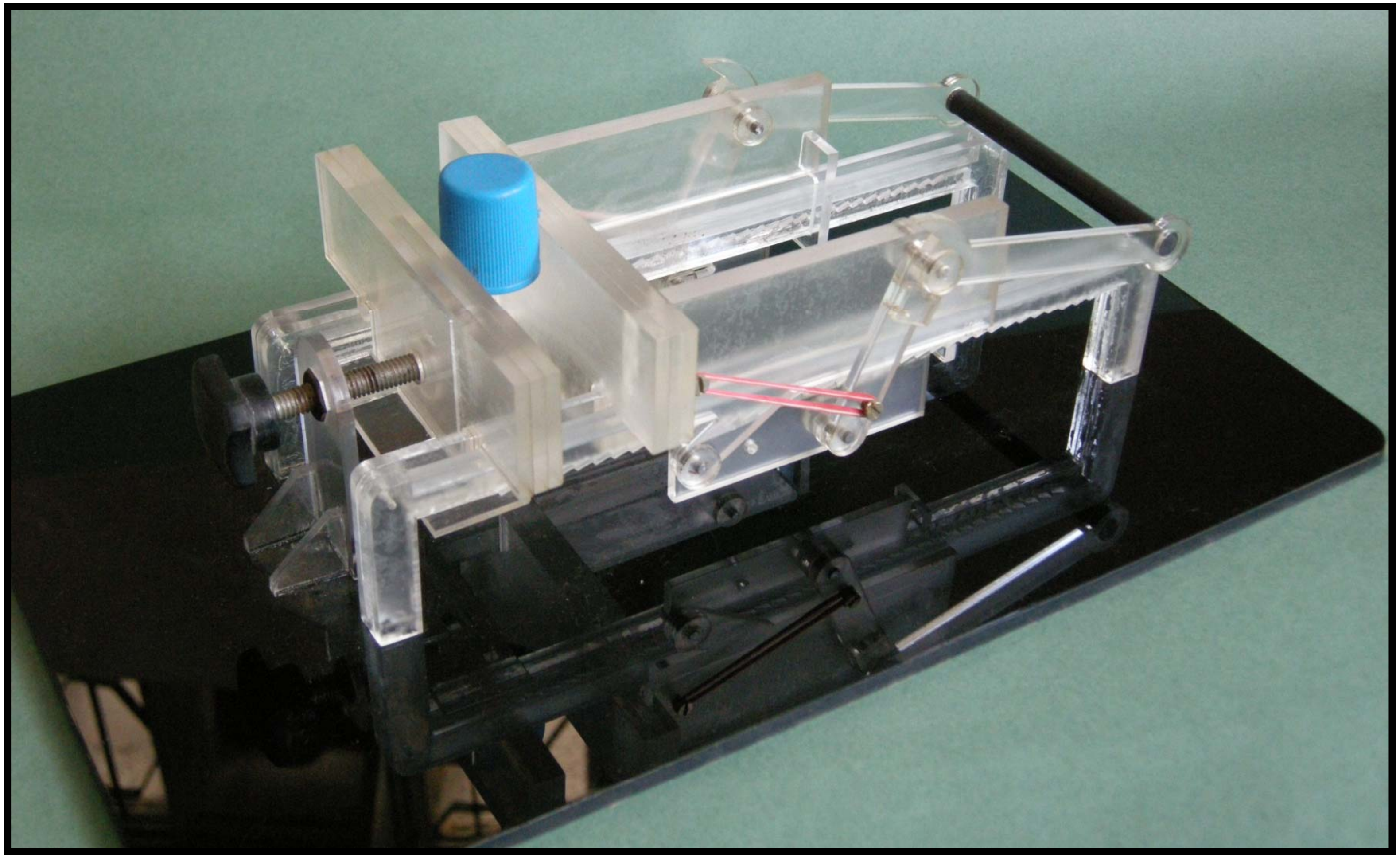




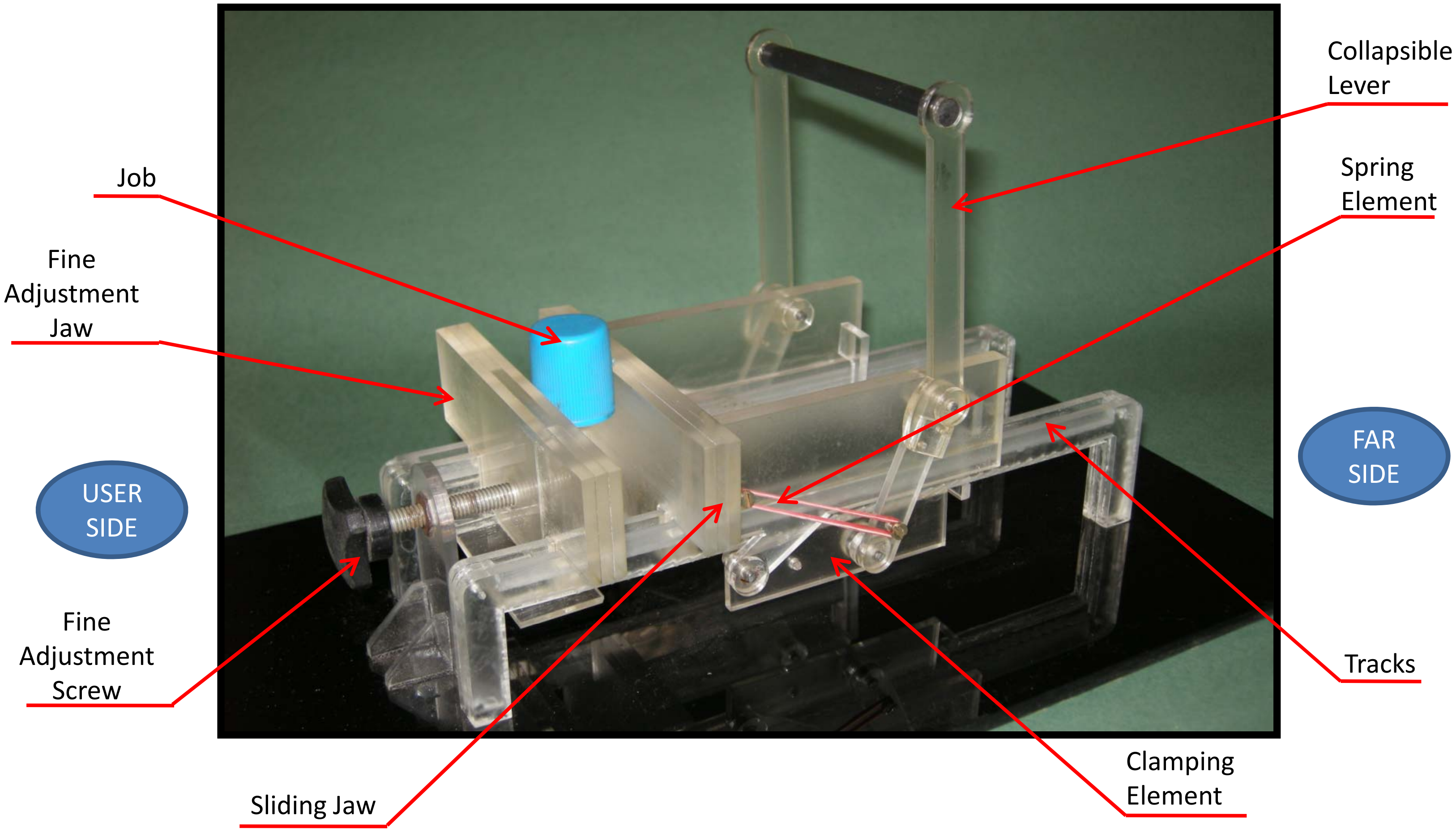


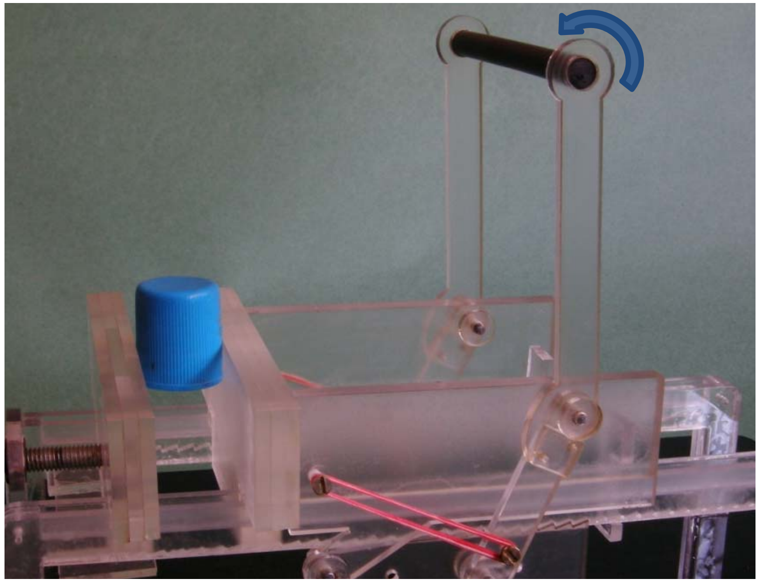
- Also following changes were made to the linkages so that both the lever and the screw control for jaw 1 is on same side.
- Here the jaw 1 slides w.r.t. the base and the jaw 2 slides on the tracks.
- The sliding motion for jaw 2 is controlled by using a lever and claw arrangement.

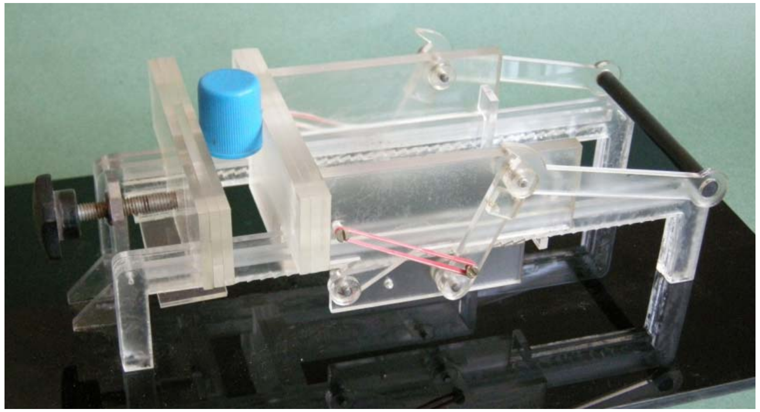
Final Concept



Components of the bench vice:







Operating Procedure:

<u>Setting (refer previous fig. for nomenclature)</u>

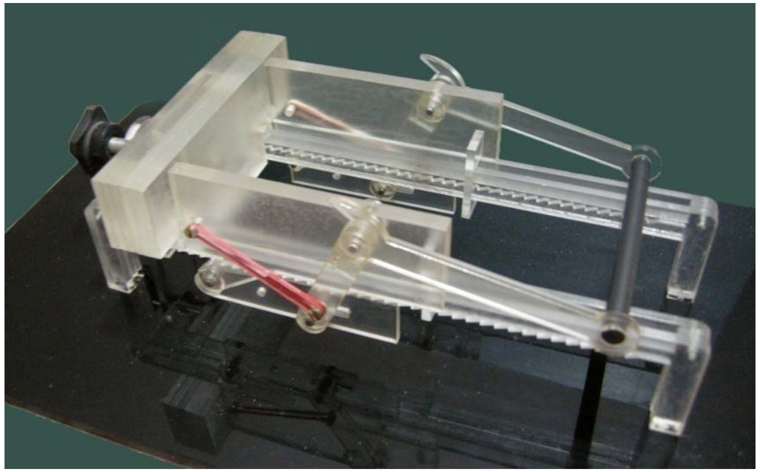
- The jaw, sliding on the tracks is released for movement along the tracks by pulling the collapsible lever towards the user side as shown in adjoining fig.
- The work piece is positioned between the two jaws and the sliding jaw is brought as close as possible to the work piece till it locks firmly when the collapsible lever is released.
- The job is then firmly clamped by tightening the screw on the fine adjustment jaw.
- While working the lever is kept is the collapsed position as shown in fig. below

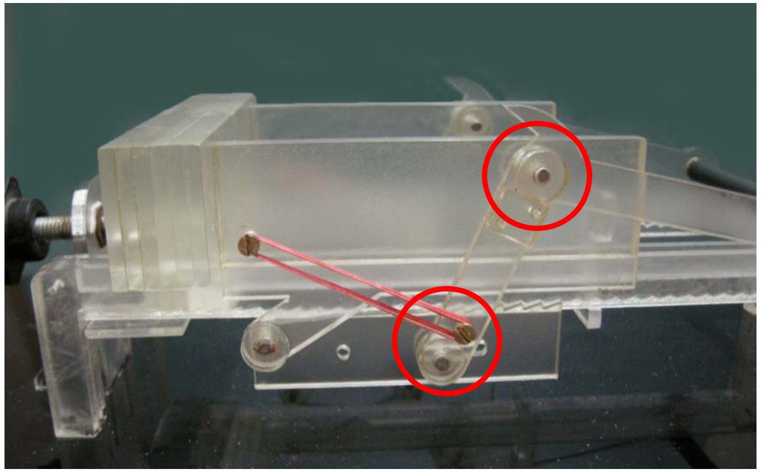
<u>Releasing & clamping</u>

- For releasing the lever is held upright and pulled towards the user side thereby releasing the sliding jaw.
- Once the setting is done for 1st piece, all that needs to be done for clamping is to place the work piece next to the fine adjustment jaw pull the lever towards the user and slide the other jaw towards the work piece. A small amount of clamping force is required to ensure perfect clamping of the work piece.

Features:

- Quick clamping and quick release.
- Constant clamping force for jobs of same dimensions
- Light weight construction
- Material efficient





Observations

Following inferences were drawn from the working model:

- While fixing the work piece some leverage is required to clamp the job tightly.
- When sliding the right jaw away from the job, the length of the lever makes it feel weak, especially at the hinge (see the circled area). This may be solved with the use of metal (tempered steel) as the material.
- The geometry seems to be fine, with linkage not being reversible i.e. force on the right jaw in either direction doesn't release the grip of the teeth.

Future Work

- There is a need to work out the position the spring.
- When the job has to be clamped with the existing setting some amount of force is required to be applied when locking the sliding jaw, proper leverage or some linkage that can aid this task needs to be worked upon.

Learning

This project has been instrumental in firming my belief in the capabilities of Bionic approach towards design. It has also helped me understand the structured approach required towards mechanism based design.

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