TO: Dr. P. Papalambros

FROM: Marc D. Hewko

DATE: 4-26-88

This package includes my final report titled "A Feasibility Study on Robotic Flexible Fixturing Systems" and the computer disk on which it is stored. If you have any questions I can be reached at my home address in Clarkston.

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In addition I made a display poster that describes the AFMF system for the lab. If you want to see the poster it will be on display in Rm #10 at the ATL.

Again, if you have any questions please feel free to contact me. I would like to wish you the best of luck in the future.
A FEASIBILITY STUDY
ON ROBOTIC
FLEXIBLE FIXTURING SYSTEMS

Automated Flexible Modular Fixturing
(AFMF)

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Department of Mechanical Engineering

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ME 490 Independent Research Project

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Introduction

A feasibility study was conducted on Flexible Fixturing Systems for robotics assembly. This report will present the results of one of the three branches of this investigation, the Automated Flexible Modular Fixturing system (AFMF).

Currently there does not exist a fully automated modular flexible fixturing system. The three modular fixturing systems that do exist, manufactured by, Bluco (parts catalog can be seen in APPENDIX), Halder and QU-CO, are all flexible, but due to their design, it is extremely difficult to automate their assembly. These systems, for example, use threaded fasteners to fix system components to a base plate. This method may be highly effective for manual assembly, but it is tedious and time consuming for an assembly robot to locate and thread threaded fasteners. With this in mind, and several other design parameters to be mentioned later, the AFMF system was developed.

Using the three primary manufacturers of modular fixturing, a comparison grid was compiled (see APPENDIX). The main objective of this task was to compare the existing fixturing systems to see how they could be simplified and still be an effective automated fixturing system that can be assembled and disassemble by a robot using a minimum number of fixturing parts without sacrificing their current effectiveness. The parts compared were divided into six categories: adapters, clamps, locaters, plates overlays and miscellaneous. In addition, part function description symbols were developed to more efficiently and easily describe each part and its function (see APPENDIX).

System Description

The fixturing system designed for robotics assembly and manipulation, AFMF, consists of a base plate which is a combination of T-slots (analog) and dowel holes (digital) openings onto which various clamping devices, end-effectors, angles and locating surfaces are oriented to fixture a work piece for machining or assembly. Each of these primitives have either male or female tees to allow connection between themselves or the base plate in many different configurations. The system advantages include:

1) Simplicity of connection,
2) Durability, 
3) Maximize robot repeatability, 
4) Flexibility, 
5) Transportability, 
6) Reasonable cost, 
7) Expansibility.

**Investigation**

From the Bluco, Halder and QU-CO comparison investigation it was determined that there are three primary functions that the AFMF system must perform to be an effective fixturing system. They are to:

1) Locate a work piece accurately, 
2) Clamp a work piece securely, 
3) Provide access for easy machining or assembly tasks.

In addition, by comparing the three systems, it was determined that six basic parts are needed to perform the three primary functions. They are:

1) Base plates, 
2) Locaters, 
3) Surface and edge bars, 
4) Clamps, 
5) Extenders 
6) End effectors.

Using these conditions as guidelines a series of prototype parts were designed.

**Basic Parts Description**

1) Base plate 
The base plate is a combination of T-slot (analog) and dowel holes (digital) openings running the entire length and width of the plate. The dowel pins
secure the primitives along the T-slot, allowing the primitives to apply a force along the direction of the T-slot. See FIGURE #1. The T-slots and dowel pin holes are all on a 2.5" x 2.5" grid spacing to maximize the system versatility.

FIGURE #1

To simplify robot insertion of system components, at the end of every T-slot row or column there is a notched out area with a flange. This is used so the robot can insert the system primitives from above and not from the side. This method makes robot insertion of primitives much easier and less risky. FIGURE #2 shows a top view of one of the insert and flanges of the base plate.

FIGURE #2
2) Locaters

Locaters are used to locate a work piece on the base plate. These are the only fixturing components that need to be machined with precision since they serve as a reference surface. The locaters are fixed to the base plate using dowel pins, therefore by knowing the dimension of the locator and work piece and the location of the dowel pin holes, any point on the work piece can be located. Several concepts were developed and can be seen in FIGURES #3-#5.

**Block Locaters**

This concept uses two rectangular blocks at 90° to each other. With this simple method, parts can be located with ease. As long as the locator location and part dimensions are known, exact locations on the work place can be found using the locaters as a reference point. FIGURE #3 shows the and identical block locater positioning a square or a round work piece.

![FIGURE #3](image_url)

Adjustable Locaters

With an adjustable locater, a locating devise is not just limited to the dowel pin hole location on the base plate. The length of the locaters be adjusted by rotating the threaded bolts with an pneumatic wrench. Guide rods are also used to provide rigidity. FIGURE #4 shows how the adjustable locaters to the square and circle used in FIGURE #3.
FIGURE #4

(1) Adjustable Locater (2)

Top View

Top View

The adaptability of the adjustable locaters to other shapes is shown in FIGURE #5.

FIGURE #5

Top View

3) Surface and Edge Bars
Surface and edge bars are used to elevate a work piece off of the base plate to provide clearance for drilling and other machining operations. Surface and edge bars can also be used as locaters in situations where clearance is needed for machining. FIGURES #6 and #7 show several different applications of surface and edge bars.
FIGURE #6

FIGURE #6 shows two different block surface and edge bars and their applications to rectangular and circular work pieces. The width of these surface and edge bars can be adjusted along a T-slot to accommodate any size work piece. The surface and edge bars are fixed to the base plate by using a male and female T-slot and dowel pins.

NOTE: Version (3) of FIGURE #6 of the surface and edge bars was shown to demonstrate that the same component can be used to fixture two different work piece shapes, but in this case, due to the sharp corners of the rectangular edge bar, there is a high concentration of pressure into the cylinder wall. This condition is unacceptable because it could damage the surface under high loading situations.

Adjustable Surface and Edge Bars
The adjustable surface and edge bars have the same function as the surface and edge bars mentioned above except their height can be adjusted by rotating the threaded bolts with a pneumatic wrench, therefore, the height can be set at different levels. This feature is most useful when the work piece has a complex shape. FIGURE #7 demonstrates the effectiveness of the adjustable surface and edge bars to elevate a circular and unsymmetrical rectangular work piece.
4) Clamps
The clamping primitives are the main building block of the AFMF system. Their purpose is to provide powerful clamping forces in as small of space as possible. They can be placed directly into the T-slots of the base plate. The clamps can be interfaced with several end effectors and stacking primitives in order to accommodate many different sizes and shapes of work pieces. Clamping force can also be applied in three direction, the X and Y directions of the X-Y plane and in the Z direction of the Y-Z plane. The X-Y plane refers to the plane parallel to the base plate and the Y-Z plane refers to the plane perpendicular to the base plate. The three principle types of clamps include:

1) Flat clamp,
2) V-clamp,
3) Round-nose clamp.

Flat Clamp
The flat clamp is used to clamp down work pieces with flat surfaces. FIGURE #8 demonstrates the use of the flat clamp.
**V-Clamp**
The V-clamp is used to clamp circular shaped work pieces. It is basically the same as the flat clamp except it has a different end effector to accommodate the shape of a circular work piece. FIGURE #9 demonstrates the use of a clamp with a V end effector.

**Round-nose Clamp**
The round-nose clamp holds down work pieces through holes in the work piece. A round-nose clamp is used when a work piece can not be clamped from the outside or it is unfavorable to clamp a work piece from the outside. FIGURE #10 shows a primitive interpretation of the round-nose clamp.
General Description of Clamps

Each clamp consists of two halves connected by a machine screw and two or four guiding dowel rods. One half of the clamp acts as a base onto which the machine screw is fixed. The other half of the clamp is free to slide along the guiding dowel rods as the machine screw is turned.

There are two clamping primitives. One clamps in the X or Y directions and the other in the Z direction. It was necessary to design two separate clamps because in each, the machine screw has to be fixed to a different half relative to the base. Therefore, when the robot uses a pneumatic wrench to actuate the clamp, the machine screw can remain stationary.

The X-Y clamp is further distinguished by the T that is part of the bottom of the front moving section. This holds it down to the base plate to prevent it from riding up when it is forced against the work piece during the clamping operation.

A 1/16" by 1" slot has been added to all four sides of the stable of the X-Y and Z clamps. These slots assure that the clamp will not slip from its own weight in the robot's gripper, therefore higher accuracy in placement and alinement of the clamps can be achieved. See FIGURE #11.
All edges of the Tees in both the X-Y and Z clamps have been chamfered to facilitate smooth movement through the T-slots. This is especially important because this operation is being performed by a robotic arm and any binding up in the T-slot would cause difficulties.

5) **Extenders**
The extenders are primitives that provide an extension for raising primitives from the base plate or extending primitives over a work piece. This includes raising a work piece, clamping primitive or end effector. Extenders are included in this system not only to allow applying a downward force to a work pieces that are taller than the Z-clamp, they also are useful for situations where it might be necessary to apply a horizontal force to an object above its base. There are three primary types of extenders. They are:

1) Angle,
2) Overhang,
3) Block.

**Angles**
Angles, because of their geometry, are the most secure and stable method of
extending a primitive above a work piece. The angle has a series of female T-slots on its front face to allow the connection of overhang extenders or Z-clamps. The angle is connected to the base plate using two male T-slot to prevent upward motion when a vertical load is applied and it is fixed to the base plate using dowel pins to prevent a horizontal motion along the T-slot. FIGURE #12 shows an entire configuration incorporating an angle as its principle extender to raise the Z-clamp high enough to allow to clamp the work piece.

**FIGURE #12**

![Side View](image)

**Overhang Extenders**

The overhang extenders are primarily to be used with the angle to provide an overhang extension over a work piece. For instance, a work piece may be very tall and wide so that a standard Z-clamp does not have the height or the reach to securely hold it. An overhang extender attached to an angle will provide the reach and the height needed to secure the work piece. FIGURE #12 shows this application.

**Block Extenders**

The block extenders are stacking primitives that provide an extension for raising primitives from the base plate. Any number of blocks can be used to raise primitives, but caution must be taken because if too many block extenders are used (2 or more) the system will become unstable and not secure a work piece. In this situation, it is recommended that an angle extender is implemented because it provides a much more stable form of raising a primitive.
6) End Effectors
The end effectors serve as the hands of the clamping devises. They can be attached to the end of the clamping primitives by T-slot connectors to accommodate many different work piece sizes and shapes. Some end effectors can also be used as locating blocks to support unstable work piece shapes on the base plate.

Though a manufacturer of this system would offer an inventory of the most universal end effectors, it is this component of the AFMF system that allows the user to customize the system to meet their specific needs.

System Configuration
FIGURE #13 shows the AFMF system at work. In this diagram, a goose neck type work piece is fixtured for a drilling operation in the Z direction at the center of its neck. Since the operation only applies a force in the Z direction and not in the X-Y plane, the work piece does not have to be clamped in the X-Y directions. Here four types of system primitives are used: three Z clamps, one support bar, one flat clamp end effector and one 90° flat clamp end effector. The support bar holds the raised portion of the work piece above the base plate while the 90° flat clamp clamps the work piece to the support bar in the Z direction. At the other end of the work piece, a flat clamp end effector is used to clamp the work piece to the base plate. Note that three identical Z-clamps are used with three different end effectors to perform two different functions of the fixturing process. This shows the versatility of the AFMF system by using identical primitives to perform different tasks.
Design Criteria

Strength
The system must be able to hold work pieces with sufficient strength to withstand forces of the target machining operations (drilling, boring, milling, profiling and facing) and assembly without movement of the work piece that would cause inaccuracy of fabrication.

Reasonable Cost
Since the cost of an automated modular fixturing system will be weighted against the cost of manual labor to fixture work pieces, it is important to keep the design simple and multi-functional.

Low Maintenance
The system should avoid components that wear quickly.
Prevent Chip Clogging
Chips from machining operations should not obstruct the system function.

Flexibility
The system should accommodate a wide variety of sizes and shapes of work pieces.

Transportability
The system should be compatible for movement within an automated manufacturing cell.

Expandable
The system should be expandable to serve the user's needs. Expanding the system should not obsolete the original system.

Elimination of High Risk Tasks
Tasks such as the insertion of a threaded component that have high risk problems such as cross threading, should be avoided in any robotic assembled fixturing system.

Precise Location of Work Pieces
Precision of location is necessary for the robot to have optimum repeatability.

Component Stability
It is necessary for the fixturing components to have flat surfaces to provide part stability for location after temporary placement.

Task Simplicity
Any task required of the robot must be simple enough to accommodate single arm operation.

Ease of Manipulation
Movement or connection of parts must be accomplished without binding.
**System Operation**

By using combinations of fixturing components many different work pieces can be held securely for manufacturing. First, end effectors are assembled to the clamping primitives. Next, directional disks, extenders, locating locks and/or end effectors are placed on the base plate in a desired location by the robot and fixed using dowel pins as needed. The work piece is then place on the base plate by the robot against any locating blocks or end effectors. The next step is to place the clamps around the work piece by sliding them along a T-slot using the robot until it has reached it desired location, then securing the clamp to the base plate using dowel pins. Finally, the robot picks up the pneumatic wrench and tightens the clamps around the work piece.

To remove fixturing, the exact same procedure is carried out except the steps are reversed. However, the system is designed to allow the work piece that has been clamped to the base plate to be palletized and transported to a new location for subsequent machining or assembly operations.

**Prototype Design**

In the APPENDIX are the drawing for several components of the wood prototype AFMF system. The dimension of the components are not included because it is difficult to determine the skill level of prototype carpenters. This permits the designer to accommodate the part tolerances to the skill level of the carpenter. An ideal tolerance for the prototypes would be 1/32" and an acceptable tolerance would be 1/16". After consultation with several prototype carpenters, it was determined that only high skilled carpenters can build a wood prototype to 1/32 of an inch of the actual specified dimensions.
References


Appendixes

1) Bluco parts catalog
2) Comparison of commercial systems
3) System configuration sketches
4) Drawings for wood prototypes
T-SLOT BASE PLATE

FOR WOOD PROTOTYPE
<table>
<thead>
<tr>
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<th>BLUCO</th>
<th>HALDER</th>
<th>MODULAR FIXTURING</th>
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</table>
Symbols

Edge Bar pg. 18

1. Support & bolted
2. Fixed

Dual Surface page 19

0

1. Support on 2 sides & bolted
2. Fixed

Adjustable Surface Bar pg. 20

1. Support
2. Adjustable

Surface Tower pg. 22

1. Support on 1 side & 1 different side, bolted
2. Fixed

Surface Tower, adjustable in height, pg. 22

1. Same as above
2. Same
3. Adjustable in height
V-Block pg 24

1. Supports by a V & Bolts
2. Fixed

V-Block pg 24

1. Supports by V & Bolts + Wire
2. Fixed

Adjustable V-Holder pg 25

1. Supports by V & Bolts!
2. Adjustable Height

V-Bar pg 25

1. Supports by V-shaped
2. Adjustable

Flat Adapter Bar pg 27

1. Thing, bolt on it, bolted
2. Adjustable
adjustment stop pg 28

1. Bolted & Adjustable
2. 360° rotation

speed clamp pg 30

1. Clamp, Bolted
2. Adjustable
3. Rotates 360°

clamping support pg 32

clamped pg 34

1. Clamps down & is Bolted
2. Adjustable

step clamp pg 35

1. Clamps downward & is Bolted
2. Adjustable
What is blüco technik?

Not only are the technical concepts and production of a fixture decisive, but also the time spent and cost to build a fixture must be considered and critically compared with the desired results.

Too little consideration is actually given to downtime and set-up time which, in fact, constitute a major cost factor.

We have attempted to find an optimum solution to these problems in general and to the reduction of set-up costs in particular. This endeavour has led us to the development of a modular fixturing system, which has found its way into workshops owing to its rigidity, accuracy, simplicity, and lower cost.

Our solution:

blüco technik Modular Fixturing Systems

516 • 412 • 310
Modular Fixturing offers multiple advantages such as time savings, low cost solutions, re-usability of fixturing elements, universal usage, and infinite application possibilities. Some of these are:

- Fixtures for prototype production or pilot runs, especially when design changes are to be expected yet.
- Small lot and spare parts production.
- Tandem fixturing utilizing the blüco modular system offers substantial reduction of machine idle time for boring mills and machining centers.

Application of blüco fixturing on turning, boring, milling, grinding, planing and special purpose machines as well as in inspection and testing departments saves time and cost. Depending on plant organization, the blüco fixture can be built by the machine operator, by the set-up man in the tool room or in the tool design department using CAD/CAM.

The blüco fixturing can also be used with pallet change systems both on conventional and NC machines. The exact positioning of the fixture on the machine table and repeatability of reference points are absolutely ascertained. Set-up time savings of up to 80% are obtainable if other fixtures can be built during the machining cycle.

The fixture originally designed for manual clamping can be easily and quickly re-built for pneumatic or hydraulic clamping.

When production is completed, the blüco fixture can be dis-assembled and the fixturing elements then remain at disposal for further use. Taking photographs and listing bills of material are convenient aid for future repeats of fixtures.

The outstanding blüco accuracy is based on a patented manufacturing process. This is essential for accurate CNC machining.

For precision, there is no alternative.

---

### Technical data of the systems

- Base plates and angles: high grade cast iron
- Plane parallelism: 0.01 mm per 500 mm
- Locating edges and surface towers are hardened to RC 60
- V-block surfaces are case hardened
- Locating edges and towers ± 0.01 mm
- Accuracy of center distance between dowel holes x y 0.01 mm per 500 mm
- Squareness ± 0.01/300 mm
- Dowel holes are case hardened
- Dowel fit to DIN 7979 m5
- All grinded surfaces roughness 0.4 μm = ∨
- Numbering of the system

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### Rundspannplatte
Round base plate

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Auf Wunsch fertigen wir Grundspannplatten entsprechend Ihrem Maschinentisch, einschließlich Indexier- und Befestigungsbohrungen

Special dimensions for your machines on request.

Unsere Abmessungen für System-Sonderplatten:
Maximum dimensions for special plates:
516 = 1550 x 950 mm
412 = 1200 x 880 mm
310 = 900 x 450 mm
### Tabelle: Doppelwinkel Kern: ausgehärtezte A1Si-Legierung

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Konsole
Large console

Material: GG 26

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### Turmkonsole
Tower console

#### Specifications

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#### Additional Diagrams
stable angle base (2 x 45 degrees of movement)

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### Surface and Edge Blocks

#### Auflage- und Anlageleisten

**Surface and edge bars**

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Schlebbare Auflage-Leisten
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Zentrierleiste
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Auflage-Türme
Multi-surface towers
Höhenverstellbarer Auflage-Turm
Surface tower adjustable in height

Distanzscheiben geschliffen
Ground spacers
Magnet-Turm
Magnetic tower

Winkel-Turm
Angle tower
Prismaturm höhenverstellbar
Adjustable V-tower

Prismaleiste
V-bar
### Anpaßwinkel
Customizing angle

Sondergrößen auf Wunsch
Special dimensions on request

### Anpaßplatte
Customizing plate

Sondergrößen auf Wunsch
Special dimensions on request

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**Blüco technik**

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**Blüco technik**

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**Adapterplatte flach**

Flat adaptor bar

**Adapterplatte hoch**

Adaptor bar

---

**Material: St 37 K**

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### Adapterplatte flach

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**Verstellanschlag**
Adjustment stop

**Spann-Leiste**
Support bar
Kugelspanner
Ball screw clamp

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**Tiefdruckspanner**

Serrated edge clamp

---

**Material:** Stahl gehärtet

---

**Tischspanner mit Adapterleiste**

Clamp with adjustable bar

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Spannschraube mit Mutter
Screw with jam nut

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Druckschraube mit Hartmetallrippelung
Carbide tipped screw

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Kugelschraube
Ball screw

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Spannleisen DIN 6314
Plain clamps

Spannleisen DIN 6315 B
U-clamps

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Spanneisen DIN 6315 C
Hand nose clamps

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Gabelspanneisen
Forked clamps
DIN 6315

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Spanneisen gekröpft
Step clamps
DIN 6316

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### Adjustable clamp iron DIN 6314 V with stud bolt

**Spannbrücke**  
Pressure bridge

### Studschraube vergütet DIN 6379  
Stud bolts, heat-treated DIN 6379
Gewindestifte
Thread pins

Scheibe gehärtet DIN 6340
Disc, hardened DIN 6340

Mutter DIN 6330 B
Nut DIN 6330 B

Verlängerungsmutter
Extension nut
**Spannseihalter**
Clamp holder

**Inbusschrauben 10 K DIN 912**
Socked head screws 10 K DIN 912

<table>
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<tr>
<th>Best.-Nr.</th>
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**Zylinderstifte m 5 mit Innengewinde DIN 7979**
Cylinder pins m 5 with female thread DIN 7979

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**Zentrierdorn**
Locating center

* D₁ = bei Bestellung angeben
  * D₁ = dimension when ordering
Műnutenstein  
B = bei Bestellung angeben
indicate "B" dimension when ordering

<table>
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<tr>
<th>Best.-Nr.</th>
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Verschlußstopfen für Gewinde- und Paßbohrung
Hole plug (ten plugs per bag)

Magnetgriff
Magnetic plug remover
How to calculate your savings and break-even point before you purchase Blüco technik modular workholding fixturing

When comparing Blüco costs to hard tooling, the break-even point in total number of fixtures is calculated using the following:

\[(A) = \text{average fixture costs (present)}\]
\[(N) = \text{number of fixtures (break-even)}\]
\[(B) = \text{Blüco purchase cost}\]
\[(I) = \text{incremental cost for each new Blüco fixture assembly}\]

The formula is:

\[B \frac{1}{A - I} = N\]

For example, the graph above is based on an average cost per dedicated fixture \((A)\) of $1500 and assumes a Blüco starter package with base plate at a purchase cost \((B)\) of $11,500. You allow 4 hours for first-time assembly of each Blüco fixture at a cost \((I)\) of $30 per hour, or $120. This brings you to a break-even point on your purchase cost after assembling only 8.3 Blüco fixtures.

\[\frac{11,500}{(1500 - 120)} = 8.3\]

If you need only 2 new fixtures per month, you will have paid for the Blüco system in the fifth month!—and these conservative estimates do not include any values for quick response time or last adjustment to engineering changes, costs for storage space, nor other factors which add to conventional fixturing costs.

See other side for Blüco fixturing features.
A "blüco" 2-D CAD database is available to run with most PC based CAD systems. A 3-D CAD database in IGES is available for the mainframe CAD systems.

These systems can generate parts lists and check cutter paths to speed the fixturing process and improve documentation. Sample data files are available on request.
blüco technik

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Telex 7 255 193 blue d