Technical University of Liberec

Faculty of Mechanical Engineering

Ahmed Elgozali

Design of special purpose modular machine

Diploma Project

2010

Technical University of Liberec

TECHNICAL UNIVERSITY OF LIBEREC
Faculty of Mechanical Engineering

Department of Manufacturing Systems

School Year: 2008/2009

DIPLOMA PROJECT

Graduate name and surname: **Ahmed ELGOZALI**

Study programme: **M 2301 Mechanical engineering**

Study discipline: **2301 T030 Manufacturing Systems**

Study direction: **Flexible manufacturing systems for engineering production**

According to the Law Digest No. 1111/1998 for the Universities, the Head of the Department of Manufacturing Systems determines you this Following Topic for your Diploma Project:

Project heading: **Design of special purpose modular machine**

Thesis Content:

1. Introduction, analysis of task parameters
2. analyse necessary steps for machining
3. specify cutting conditions for material machined and each operation
4. design basic layout of operations
5. design fixture and location
6. select and assemble available modules from catalogue
7. calculate sequence time and economy

Text: min 40 pages of text
Drawings: 5 + according to necessity

References:

/1/ Modular Units catalogue

/2/ Users Manual, company know-how

/3/ TLUSTÝ, G.: Manufacturing Processes and Equipment,
ISBN 0-201-49865-0, Prentice Hall, NJ. 2000

/4/ MADISON, J.: CNC Machining Handbook,
ISBN 0-8311-3064-4, Industrial Press, NY, 1996

/5/ KOENIGSBERGER, F: The Selection of Machine Tools,
IPE, Rochester, G.B. ISBN 0 85510 019 2

/6/ HUBKA, V.: Engineering design, Heurista 1992, Ontario CND,
ISBN 3 85693-026 4

Supervisor: Prof. Ing. Přemysl Pokorný, CSc. TUL, FS, KVS Liberec

Consultant: Ing. Petr Zelený ,Ph.D. TUL, FS, KVS Liberec

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Prof. Ing. Přemysl Pokorný, CSc.
Department Head

Prof. Ing. Petr Louda, CSc.
Dean

V Liberci 27.2.2009

Validity of this project task is 15 months from the date above. The terms of submission are given for each academic year by particular study schedule.

TECHNICAL UNIVERSITY OF LIBEREC

Faculty of mechanical engineering

Department of manufacturing systems **school year: 2009/2010**

Study programme: 2301T030 Manufacturing Systems
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Design of special purpose modular machine

KVS-VS-178

Elgozali Ahmed

Supervisor: prof.Ing.Přemysl Pokorný,CSc.
Consultant: Ing. Petr Zelený, Ph.D. TUL, FS, KVS Liberec

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Annotation:

The diploma work deals with methodology and example of one purpose automated machine design. It includes analysis of work piece technology, selecting position and sequence of operations; cutting conditions calculation with definition of power requirements. There are selected modular units; and assessment made up on technical and economy features.

Anotatce:

Diplomová práce se zabývá metodikou a návrhem jednoúčelového stroje. Zahrnuje analýzu obrobku, návrh technologie, výběr pozic a sled operací, řezné podmínky, výpočty pohonu(síly, výkon). Jsou vybrány modulární jednotky;a provedeno technicko ekonomické hodnocení.

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Contents:

1. Introduction

One purpose Machine is such a machine which is designed to produce one kind of a certain workpiece.
Depending on annual production volume; according to number of parts produced per time unit **one purpose machines** are used in large-series and mass production of work-pieces e.g. form of boxes, plates, housing, levers, etc. The operations performed are mainly various types of drilling, reaming, tapping, boring, and milling. The complete, rather complex set of operations is distributed to a number of stations. In each station one or more tools work in a cycle and all the sub-operations are carried out simultaneously on one work-piece in each station. Each work-piece is stationary during the operations and is moved to the next station between the cycles. Thus, each work-piece passes subsequently through all the stations, and once per cycle one work-piece is completed, and one work-piece inters the line or machine.
For smaller number of operations that are divided among a small number of stations (essentially between two and ten), such machine is based on a rotary indexing table with the stations arranged on its periphery and the work-piece clamped in fixtures or pallets on the table. This arrangement is called a dial-index machine. The operations performed consist of drilling and reaming a number of holes.
On the following figure 1.1 is shown some example of arrangement of substructure with rotary table.

Fig.1.1. An example for arrangement of substructure and a rotary table on one purpose machine

1.1. Task Description

The task is to design a unique purpose machine which will machine the work piece given (block of aluminum alloy) Figure 1.2.1 and will produce a finished complex part see-Figure 1.2.2 (appendix technical drawing).

Material of the work-piece according to Czech standards (ČSN) is a light aluminum alloy of class 424256, with machine-ability class 10d, and the specific cutting force p = 1000 [MPa]. And R_m within the range of 180-360 [MPa]

Machine should satisfy the following conditions:
1. Drill 4 holes of diameters 1x8 and 3x4.2 mm from one side and drill 2 holes of diameter 5 mm from the other side and also make metric threading M5x0.8 in 3 holes at the first side.
2. Required output: 2,000,000 pieces per year (mass production)

1.2. Work piece analysis

Work piece before machining semi product is a block of aluminum alloy with the dimensions of 35x22x15 millimeters and it is illustrated in the picture in figure 1.2.1:

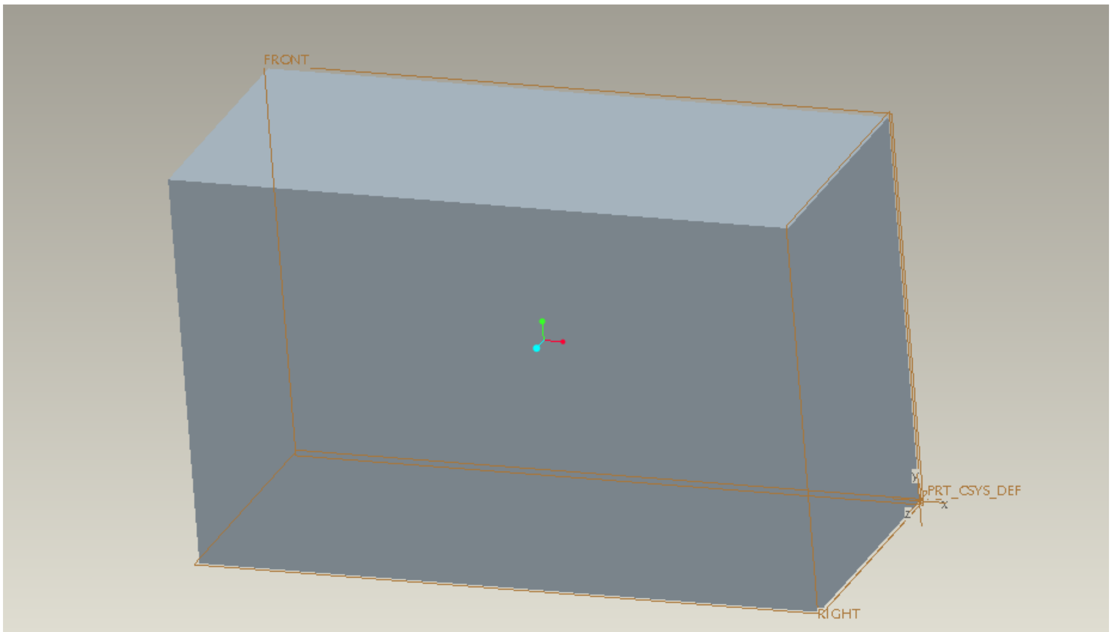

Figure1.2.1. picture of raw part

After applying different technology processes the final machined product should include machined holes like on the following figure 1.2.2

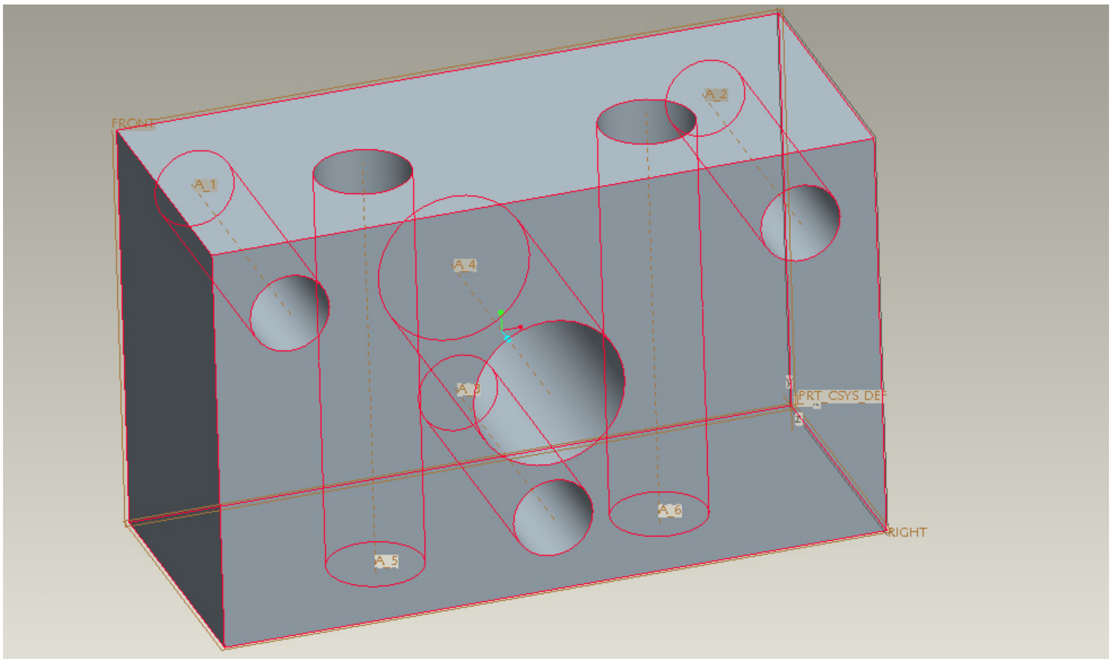

Fig.1.2.2. picture of finished product

	Operation	Of length (depth)
A1 -front face	Drill 1x ø 8[mm]	15[mm]
A2,A3,A4 -front face	Drill 3x ø 4.2[mm]	15[mm]
A5,A6 -Top face	Drill 2x ø 5[mm]	22[mm]
A2,A3,A4 -front face	Thread 3xM5x0.8	15[mm]

Table 1.1.Holes marking

Remark: for simplicity holes on the product will be marked with characters A1, A2, A3, A4, A5 and A6.

Front face of product:

Contains one hole with diameter of Ø8 millimeters and three holes of ø4.2 see figure 1.2.3 illustrated bellow:

Top face of product: There are two holes with diameter Ø5 millimeters as it is illustrated in figure 1.2.3

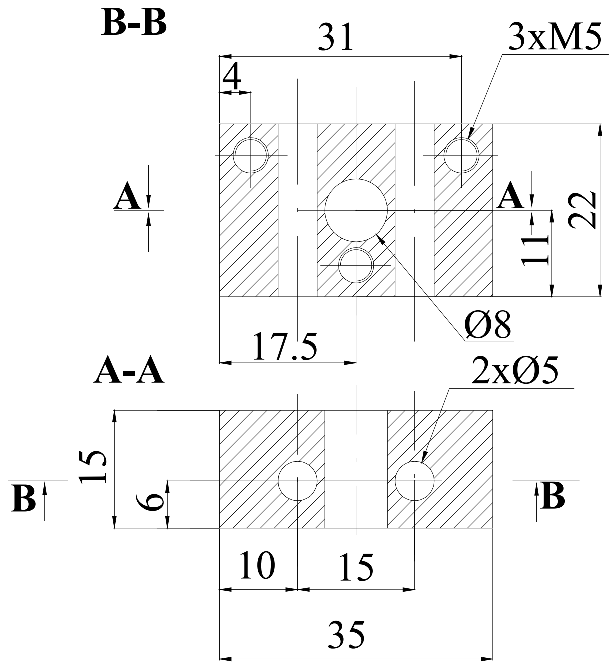

Fig.1.2.3. Front and Top faces of product

Threads:

In the final complex part there are from the front view four holes. Hole Ø8 is without any threading, but these three holes ø4.2 have internal metric thread of type (M5x0.8). The two holes from top view are without threading or any additional features.

2. Analysis of machining

The technology of one purpose machine is most suitable for drilling, tapping and milling.
In this case The One Purpose Machine represents the right technology selection because of:
1. The high number of required products (mass production of 2mil. pieces per year).
2. The limited number of operations required for machining.
And the automation here should fall under the rigid (hard) automation category.

2.1. Cutting operations and tool selection

The cutting operations, often referred to as ‘’chip removing.’’ Represent the largest class of manufacturing activities in engineering production, especially in the

production of all kinds of machines. In this case the special purpose machine should run drilling and make threading. Small diameter holes (smaller than 12 mm) need High Speed Steel twist drills, There are selected twist drills of type Drill-10 ČSN 221121 HSS which mostly used as a common cutting tool for drilling holes with diameters from 0.25 to 50 mm. They are mostly made of high-speed steel in one piece. The twist drill has two cutting (chisel) edges and two flutes to provide space for the clearing away of chips.
The characteristic dimension of drill is the diameter (d) and length (l).

2.2. Sequence of operations

2.2.1. Positioning and fixing work piece

Fixing the work piece can be done automatically or manually.
It will be done manually using an eccentric lever on a mechanical jack support.

2.2. 2. Drilling of Ø 8 [mm] (A1)

Drill a hole of Ø 8 millimeters through depth of 15 mm.

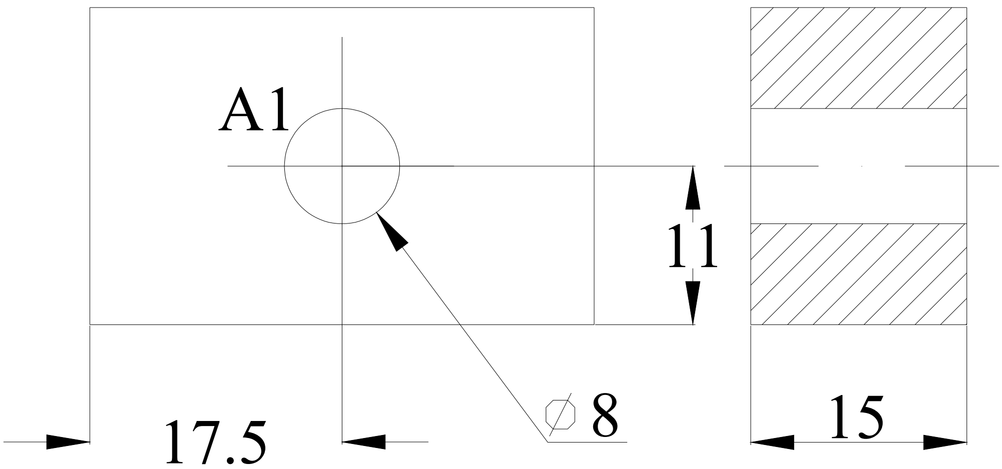

Figure 2.1 Drilling first hole ø 8 (mm)

Possibility: This Process to be done using a drilling unit of single spindle type VHJP10 MULTIPOST catalogue- (see figure 2.2 illustrated bellow):

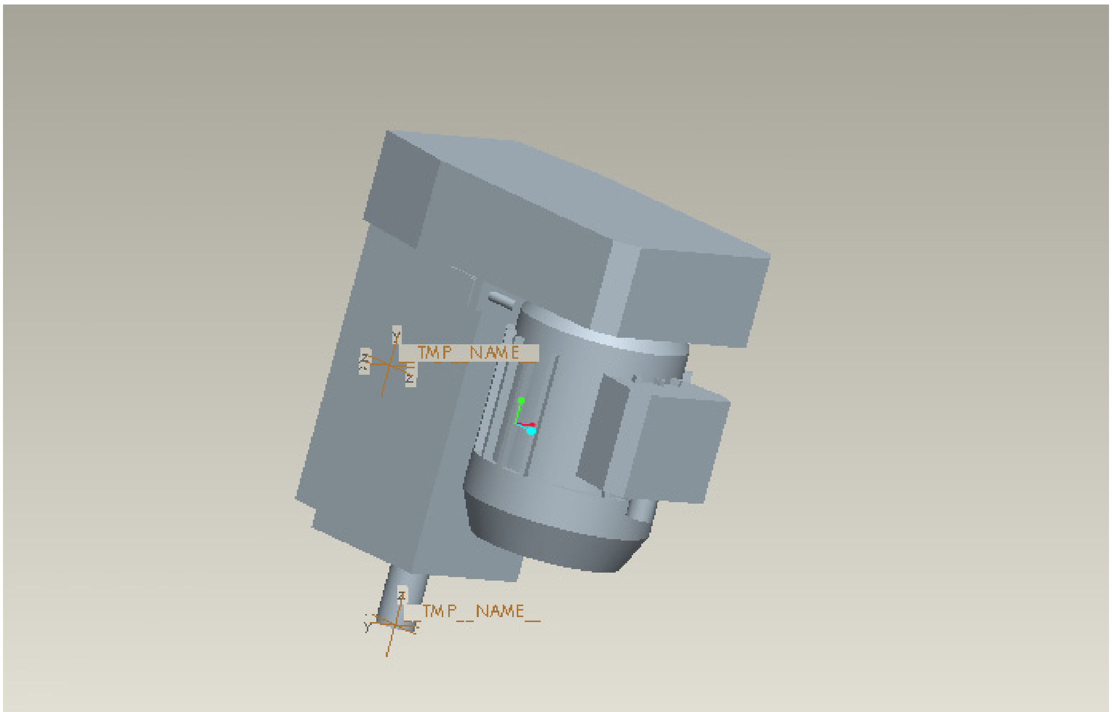

Figure 2.2.Hydraulic Drilling Unit VHJP-10

2. 2.3. Drilling of Ø 4.2 [mm]

In the front face there are three similar holes with diameter of Ø 4.2 mm.
Machining Possibilities:

1. Using a multispindle drilling head with three drills, but the minimum axis distance between holes should be at least like the one given by the manufacturer SUHNER in the table attached in appendixes 05 and 06.
2. Using a multispindle drill head with two drills to make two holes at one station and cut the third hole separately in another station.

Checking the minimum axis distance(Y) on Part:

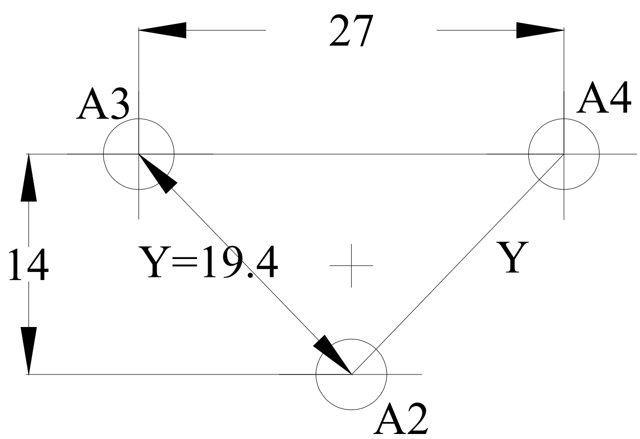

Figure 2.3 holes of ø 4.2 (mm) on the part

$$Y^2 = 13.5^2 + 14^2 = 378.25$$

So minimum axis distance between holes Y=19.4 [mm]

Calculation of minimum axis distance on the Head (MH 313) SUHNER:

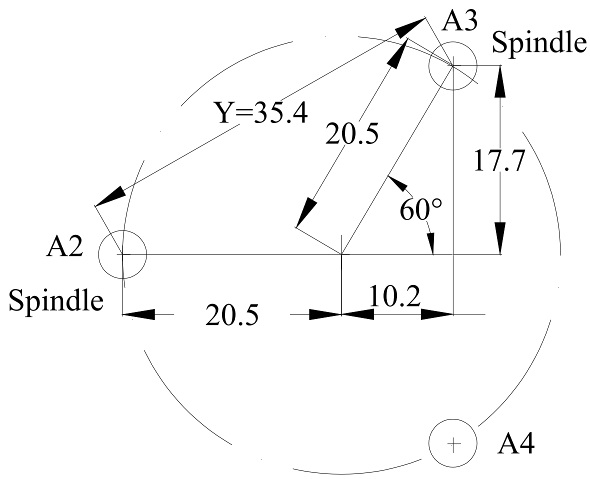

Figure 2.4 Adjustment range on SUHNER head (MH 313)

Minimum axis distance Y is calculated according to given minimum adjustment range (SUHNNER multi drill head parameters table in appendix):

$$Y^2 = (20.5 + 10.25)^2 + 17.7^2 = 1258.85$$

Minimum axis distance Y= 35.4 [mm]

According to manufacturer SUHNER the distance "y" on the picture above is bigger than distance "Y" on the part, so multispindle drill head with three drills is not applicable.

So the second possibility will be chosen to drill these holes.

Drill hole of ø 4.2 mm through depth of 15 mm.

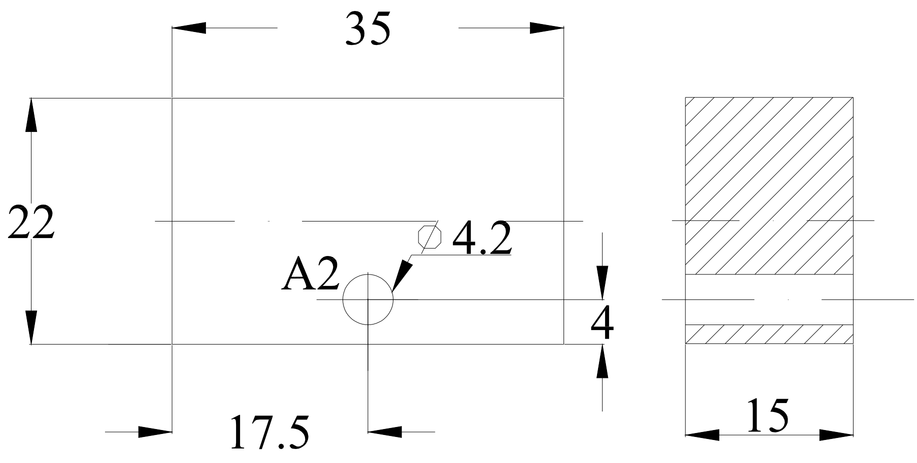

Figure2.5 drilling the first hole of ø4.2 (mm)

2. 2.4. Drilling twice Ø 4.2 [mm] (A3, A4)

Comparing the minimum axis distance of holes A3 and A4 on the product (27 mm) with the minimum axis distance given by the manufacturer SHUNNER (13.5 mm) in parameters table of multispindle head with two drills in appendix. A multispindle drill head (MH 203) with two drills is applicable.
Drill two holes of Ø 4.2 mm through depth of 15 mm.

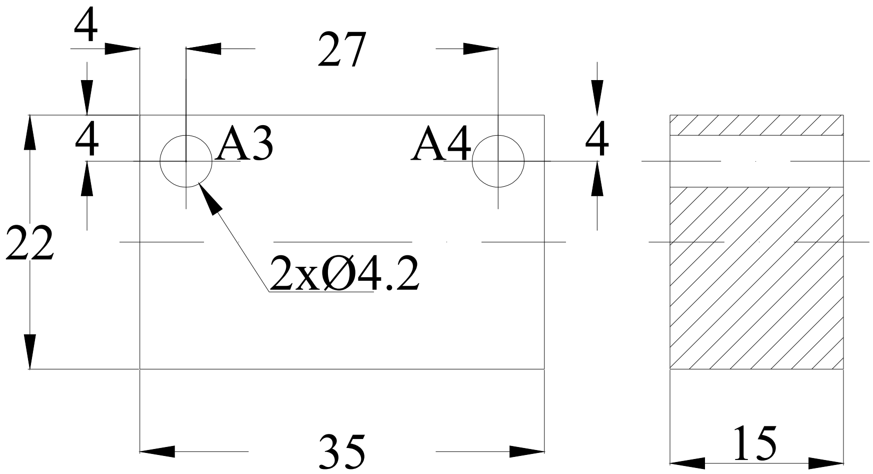

Figure2.6. drilling two holes of ø4.2 (mm)

2.2.5. Checking the holes of ø 4.2 mm

In this station there is checking unit consisting of a sliding body attached to three checking solid cylinders of ø 4.2 mm and length of more than 15 mm via a pneumatic rod. When jack support is at the position unit moves towards the work piece and the three checking cylinders approach the three holes (A2, A3, A4) if they go through the holes, then it is good and the unit moves back to start position. At least if one of the holes is not drilled properly so one of the cylinders will push back the stop switch via the pneumatic rod and that will cancel the machine cycle immediately. This arrangement is shown in the following figure:

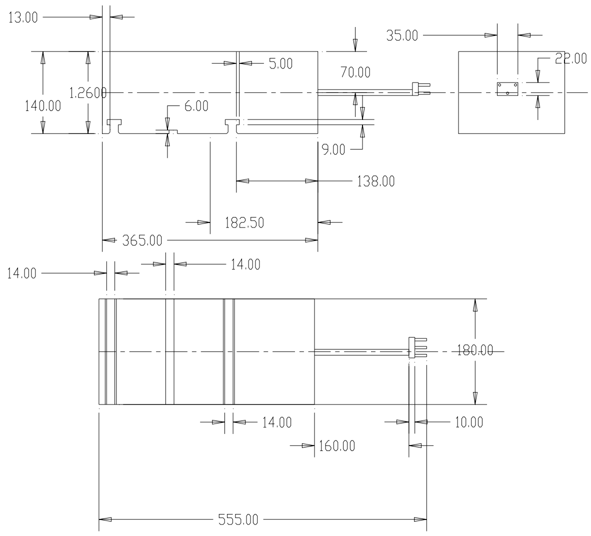

Figure 2.7 Checking unit of drilling ø4.2 mm

2. 2.6. Drilling of 2xØ 5 [mm] (A5, A6)

In the top face there are two similar holes with diameter of Ø 5 mm.
Machining Possibilities:

1. Using a multispindle drilling head with two drills, but the minimum axis distance should be at least like the one given by the manufacturer SUHNER in the table of parameters of multispindle drill head with two drills attached in appendix.
2. Each hole separately.

Checking minimum axis distance for a multispindle drill head with two drills:
Checking axis distance between holes on part:

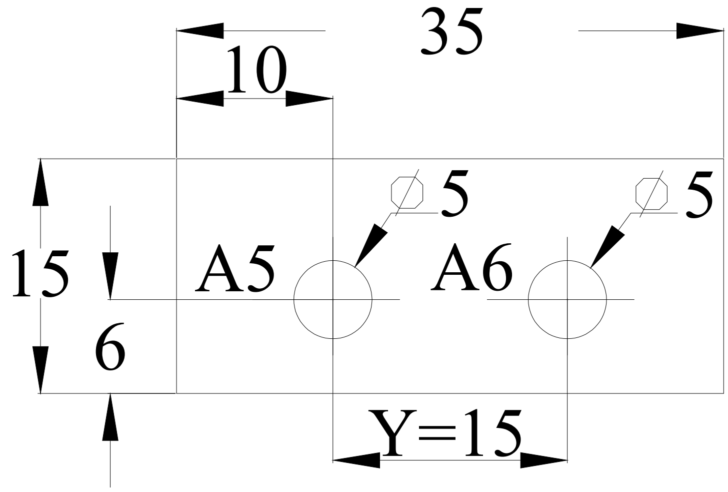

Figure 2.8 Holes of ø5 (mm) on the product

Minimum axis distance on the Head (MH 203) from SUHNER catalogue:

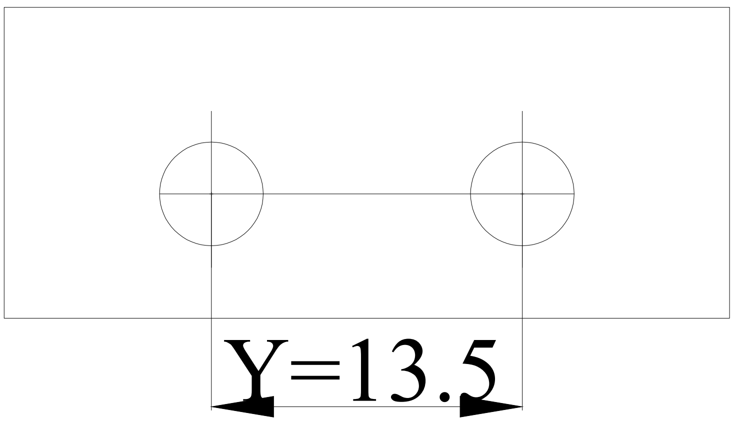

Figure 2.9 Minimum axis distance on SUHNER head (MH 203)

The minimum distance “Y” between the two holes is 15 [mm], and it is bigger than minimum distance “Y” on multispindle head of SUHNER, see appendix. So the multispindle drill head with two drills is applicable.
So the first possibility will be chosen to drill these holes.
Drill two holes of Ø 5 (mm) through depth of 22 (mm).

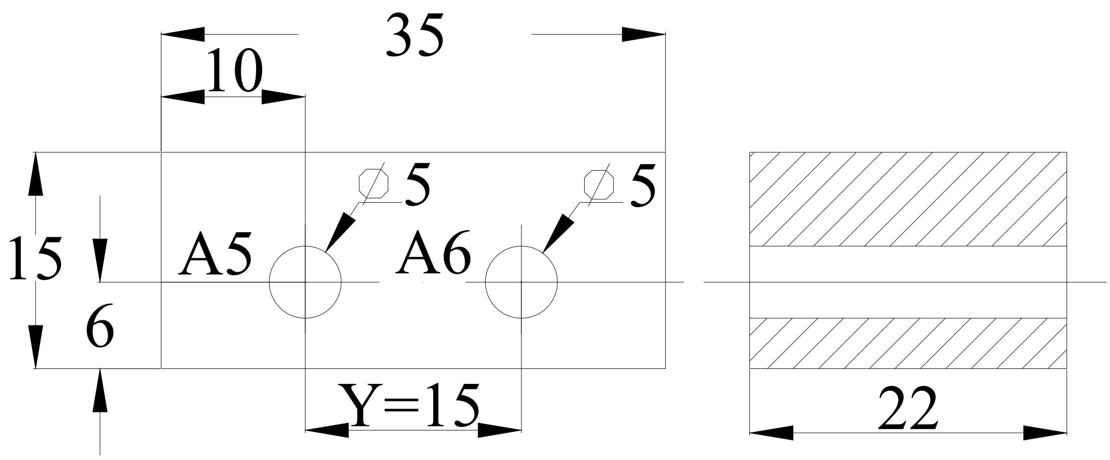

Figure 2.10.Drilling two holes of ø5 (mm)

This process will be done using the SUHNER multispindle drill head MH 203 of, it is illustrated on the following picture:

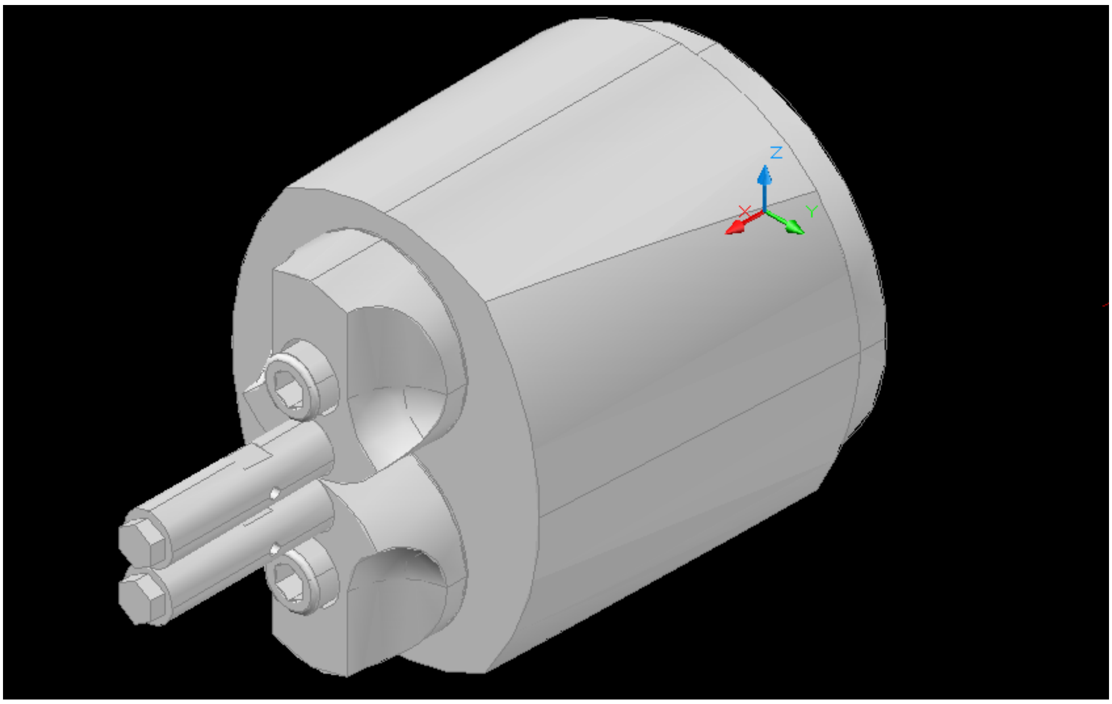

Figure 2.11 SUHNER Multispindle drill head MH 203

2. 2.7. Tapping M5x0.8

On the front face there are the three holes (A2, A3 and A4) with threading M5x0.8. Possibilities of machining:

1. Using a multispindle tapping head with three tappers.
2. Machining each thread separately.
3. Using a multispindle tapping head with two tappers to cut thread at once in only two holes and machining the third thread separately.

According to SUHNER minimum axis distance for multispindle head the three spindle tapping head is not applicable because of that the minimum axis distance “Y” on the head MH313 is bigger than the minimum distance “Y” on the product, see checking the minimum axis distance mentioned before for drilling the same holes (A2, A3 and A4).

Also machining each thread separately is not good for the machine design because of the total possible number of positions allowed on the rotary table used.

The best choice is the third one. But firstly the minimum axis distance between holes on product should be compared to the distance on the SUHNER MH 203 multispindle head.

On product:

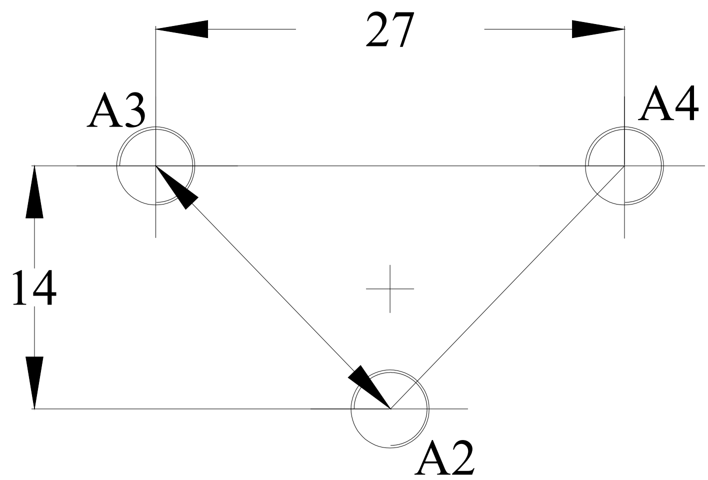

Figure 2.12Threads on product

On the multispindle head MH 203:

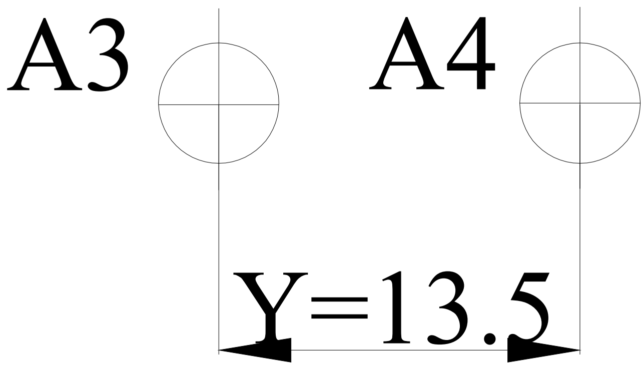

Figure 2.13 Minimum axis distance on multispindle SUHNER head MH 203

As it appear in the figures above the minimum adjustment distance on the SUHNER head MH 203 is 13.5 (mm) which is less than the distance between holes A3 and A4 (27 mm),So multispindle head MH 203 of SUHNER is applicable.

Cut thread M5x0.8 at depth of 15 mm through the hole (A2).

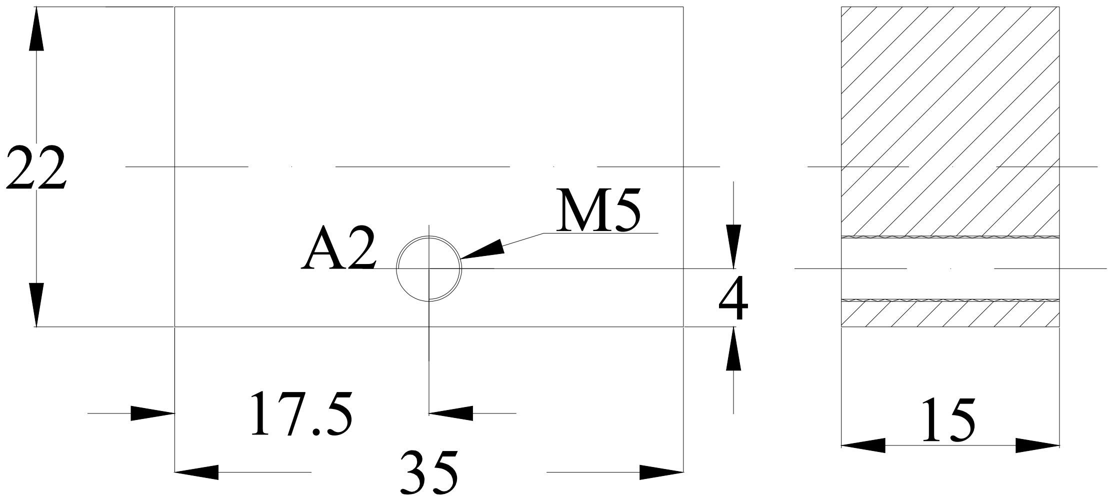

Figure 2.14 Cutting thread M5x0.8 on hole A2

2. 2.8. Tapping twice M5x0.8 on holes (A3, A4)

Cut twice thread M5x0.8 at depth of 15 mm through the holes (A3 and A4).

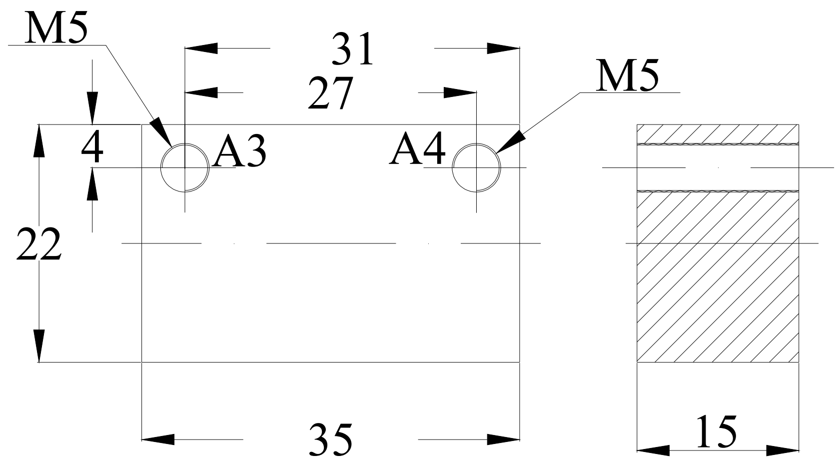

Figure 2.15 Cutting twice thread M5x0.8 on holes A3 and A4

And since the work piece material is a light aluminum alloy with Rm in the range of 180-360 [MPa], so according to Czech standards the recommended cutting tool will be a Tapper 22 3074 M 5.0x0.8 NO 2N., will be attached to tapping head (MH 203) which is attached to unit (ZJ-1600) from MULTIPOST catalogue- see figure 2.15 illustrated bellow:

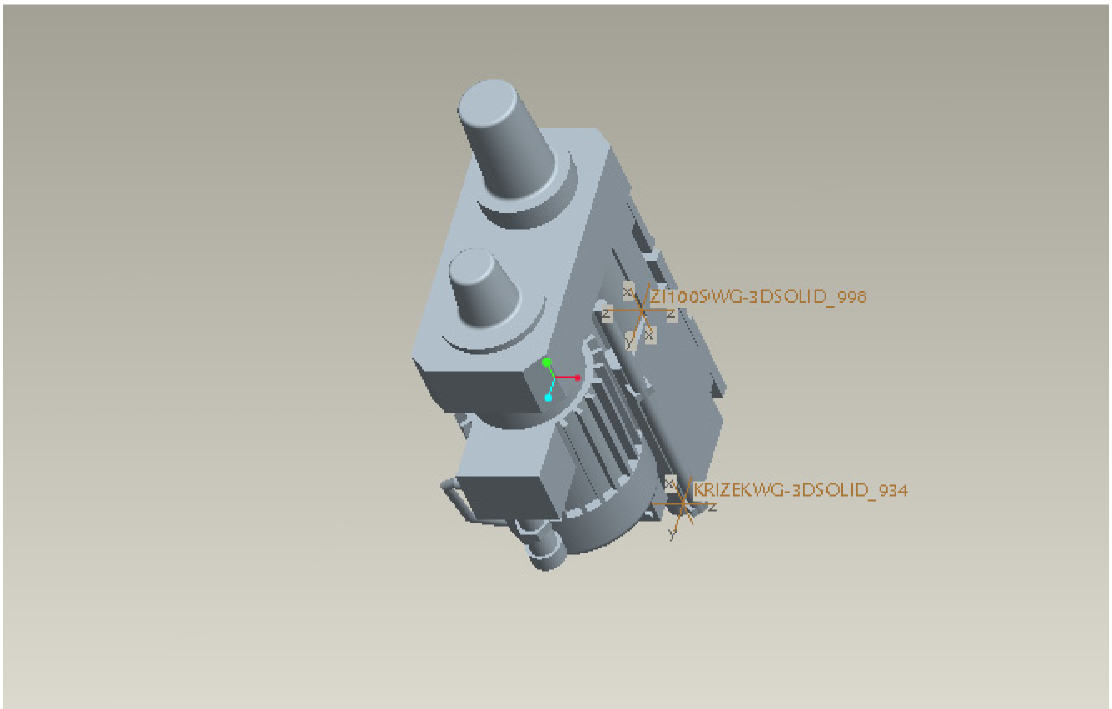

Figure2.16 Tapping Unit ZJ16-100

3. Specification of cutting conditions

The reason of establishing these calculations is the design specification of motors and transmissions (drives) for the machine units according to modular available and consequently for the whole machine.
The total required power is the sum of individual required powers of machine units taking in account efficiency of transmission which is given -according to vendor recommendations.

3.1. Cutting Conditions

According to the cutting conditions table for drilling given in appendix the following cutting conditions are recommended for drilling.

D [mm]	F_r [mm/rot.]	N [rot/min]	V [m/min]
4.2	0.10	3135	39.4
5	0.12	3170	49.8
8	0.18	1900	47.8

Table 3.1 cutting conditions for drilling

And according to cutting conditions table for tapping given in the appendix the following cutting conditions are recommended for tapping.

M [mm]	D [mm]	F_r [mm/rot]	N [rot/min]	V [m/min]
5	4.2	0.80	560	8.8

Table 3.2 cutting conditions for tapping

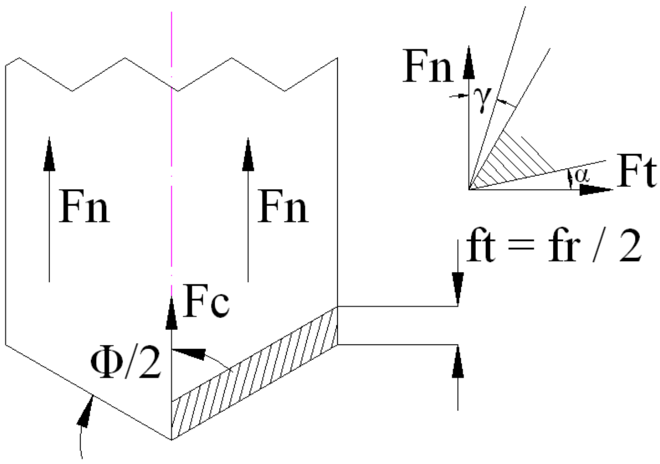

Figure 3.2 Forces on a drill

The thrust (axial) force F_a necessary to feed the drill into the cut is the sum of the two normal forces **F_n** and the central force **F_c on the cutting chisel edge. The force** F_c depends strongly on the length of the chisel edge b, but for the common condition the following formula (3.7.) can be used that assesses the total thrust (feed force) to be about one half of the sum of tangential cutting forces F_t; correspondingly,

$$F_a = 0.5\,(2\,F_t) = \frac{pdf_r}{4}\ F_a(N),\ p\left(N/_{mm^2}\right),\ f_r(mm) \quad (3.1.)$$

The value of –material; which is given previously in chapter (1.1.) can be used for p, where p is the specific resistance.

At this stage it is sufficient to say that in the first approximation the main force component is tangential to the cut surface at the point of cutting and as such falls into the direction of the cutting speed v; there for, it is the power-producing component. This component F_t is proportional to chip area A:

$$F_t = pA \quad (3.2.)$$

In this relationship p is the "specific cutting resistance,'' and it is primarily determined by the material being cut (Aluminum alloy).

$$F_t = \frac{pdf_t}{2} = \frac{pdf_r}{4} \qquad (3.3.)$$

Where:

$$F_t\ (N)$$
$$p\left(N/_{mm^2}\right)$$
$$d\ (mm)$$
$$f_r(mm)$$

Where F_t = tangential cutting force, p = specific cutting resistance.

Relationship between diameter [d] of the hole required and the rotational speed [v] is given by the following formulae;

$$n = \frac{1000\ v}{\pi\ d} \qquad (3.4.)$$

The torque is

$$T = \frac{F_t d}{2} \quad (3.5.)$$
$$T(Nm)$$
$$p\left(N/_{mm^2}\right)$$
$$d\ (mm)$$
$$f_r\ (mm)$$

And the power is:

$$P = \frac{F_t * v}{60 * 1000 * \eta} \qquad (3.5.)$$

$$P(KW), F_t(N), v\ \left(\frac{m}{min.}\right)$$

3.2.1. Calculation of drilling of Ø 8 [mm]

According to Czech standards the following cutting conditions from table 3.1.are recommended.
Feed f_r = 0.18 [mm/rot.]
Number of rotations n = 1900 [rot. /min]
Cutting speed v = 47.8 [$^m/_{min}$]

The tangential component of cutting force should be calculated from equations (3.3.) -which as mentioned previously required for developing the power, and it is as follows:

$$F_t = \frac{pdf_t}{2} * \sin\left(\frac{\Phi}{2}\right) = \frac{pdf_r}{4} * \sin\left(\frac{\Phi}{2}\right)$$

Where F_t is the tangential cutting force, p is the material cutting resistance, d is the diameter of the hole required to drill, f_r is the feed and Φ is the point angle of the drill.

Substituting:

$$F_t = \frac{1000 * 8 * 0.18}{4} \sin(60) = 311.8 \text{ [N]}$$

Torque Calculation for drilling of Ø 8 [mm]

From equation (3.5) $T = \frac{F_t * d}{2} = \frac{311.8 * 8}{2} = 1247.07\ [Nmm]$

Where T is torque in [Nmm], d is the diameter of hole in [mm], F_t is the tangential force in [N].

Power Calculation drilling of Ø 8 [mm]

$$P = \frac{F_t * v}{60 * 1000 * \eta}$$

Where P is the power in [KW], F_t is the tangential force in [N],v is the velocity in [m/min.] and η = 0.8 is the motor efficiency.

And I get:

$$P = \frac{311.8 * 47.8}{60 * 1000 * 0.8} = 0.31\ [KW]$$

So according to technical data from manufacturer (Elktrim) at appendix 08 motor type will be used in this unit is Sg 71-2A which has power of 0.37 [KW].

3.2.2. Calculations of drilling of Ø 4.2 [mm]

According to Czech standards the following cutting conditions from table 3.1.are recommended.
Feed f_r = 0.1 [mm/rot.]
Number of rotations n = 3135 [rot. /min]

$$n = \frac{1000\ v}{\pi\ d} \qquad (3.4.)$$

And so substituting in equation (3.4)

$$3135 = \frac{1000\ v}{\pi\ 4.2}$$

Follows:

$$v = \frac{3135 * \pi * 4.2}{1000} = 41.37\ \left({}^{m}/_{min}\right)$$

Cutting Speed v = 41.37 [m/min]

Cutting force calculation for drilling of Ø 4.2 [mm]

$$F_t = \frac{1000 * 4.2 * 0.1}{4} \sin(60) = 90.93\ [\text{N}]$$

Where F_t is the tangential cutting force, p is the specific cutting force, d is the diameter of the hole required to drill, f_r is the feed and Φ is the point angle of the drill.

Torque Calculation for drilling of Ø 4.2 [mm]

From equation (3.5) $T = \frac{F_t * d}{2} = \frac{90.93*4.2}{2} = 190.96\ [Nmm]$

Where T is torque in [Nmm], d is the diameter of hole in [mm], F_t is the tangential force in [N].

Power Calculation for drilling of Ø 4.2 [mm]

$$P = \frac{F_t * v}{60 * 1000 * \eta}$$

Where P is the power in [KW], F_t is the tangential force in [N], v is the velocity in [m/min.] and η = 0.8 is the motor efficiency.
Substituting:

$$P = \frac{90.93 * 41.37}{60 * 1000 * 0.8} = 0.078\ [KW]$$

So according to technical data from manufacturer (Elktrim) at appendix 08 motor type will be used in this unit is Sg 56-2A which has power of 0.09 [KW].

And since in the next process of drilling two holes of Ø 4.2 [mm] a multispindle drill head of SUHNNER M 203 will be used, so the total power of motor will be calculated as follows: $P_{total} = 2 * 0.078 = 0.156\ [KW]$
And according to technical data given by manufacturer Elektrim in appendix motor used for this process will be Sg 63-2A which has the power of 0.18 [KW].

3.2.3. Calculations of drilling of 2xØ 5 [mm]

According to Czech standards the following cutting conditions from table 3.1.are recommended.
Feed s = 0.12 [mm/rot.]
Number of rotations n = 3170 [rot. /min]
Cutting Speed v = 49.8 [m/min]

Cutting force Calculation for drilling of 2xØ 5 [mm]

$$F_t = \frac{1000 * 5 * 0.12}{4} \sin(60) = 129.90\ [\text{N}]$$

Where F_t is the tangential cutting force, p is the specific cutting force, d is the diameter of the hole required to drill and f_r is the feed.

Torque Calculation for drilling of 2xØ 5 [mm]

From equation (3.5) $T = \frac{F_t * d}{2} = \frac{129.9 * 5}{2} = 324.76\ [Nmm]$

Where T is torque in [Nmm], d is the diameter of hole in [mm], F_t is the tangential force in [N].

Power Calculation for drilling of 2xØ 5 [mm]

$$P = \frac{F_t * v}{60 * 1000 * \eta}$$

Where P is the power in [KW], F_t is the tangential force in [N], v is the velocity in [m/min.] and η = 0.8 is the motor efficiency.

And I get:

$$P = \frac{129.9 * 49.8}{60 * 1000 * 0.8} = 0.135\ [KW]$$

But in this station two holes are being machined at once, so the total power for the process I:$P_{total} = 2 * 0.135 = 0.27[KW]$
So according to technical data from manufacturer (Elktrim) at appendix motor type will be used in this unit is Sg 71-2A which has power of 0.37 [KW].

3.2.4 Calculation for cutting of metric thread M5x0.8

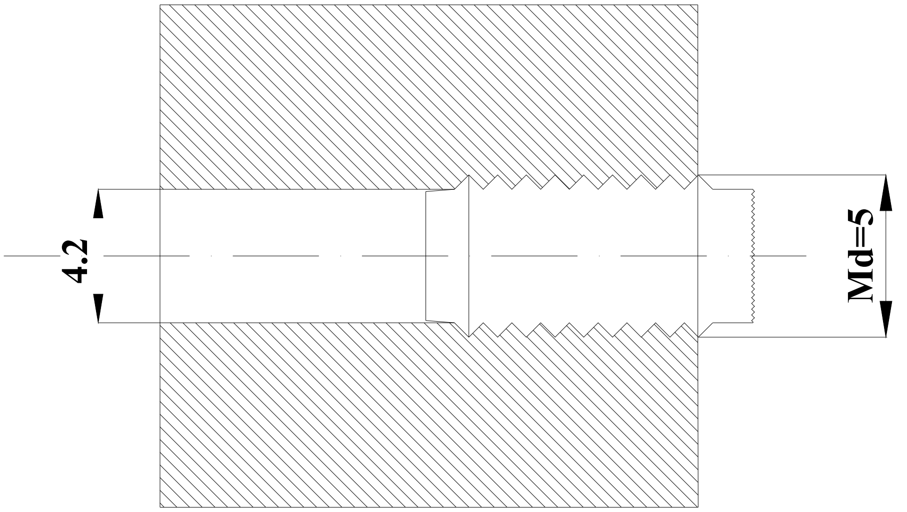

Fig.3.3. Metric thread

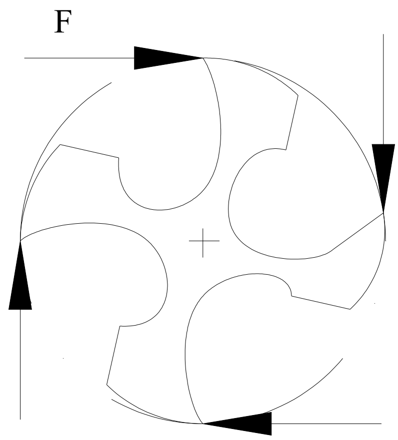

Figure3.4. Tapper 22 3070

Feed f_r= 0.8 [mm/rot.] according to Czech standards (table 3.2)

Recommended number of rotations n = 560 [rot. /min], but only 500 [rot/min.] will be used in order to increase tool life time.

And from it the speed v is calculated:

$$v = \frac{500 * \pi * 4.2}{1000} = 6.6 \left({}^{m}/_{min} \right)$$

Cutting force Calculation for tapping of M5x0.8

$$F_t = pA \quad (3.2.)$$

$$A = \left(\frac{5-4.2}{2}\right) * 0.8 * 8 = 2.56[mm^2]$$

And so the tangential cutting force is:

$$F_t = 1000 * 2.56 = 2560 \text{ [N]}$$

Where F_t is the tangential cutting force, p is the specific cutting force, d is the diameter of the hole required to drill and f_r is the feed.

Torque Calculation for tapping of M5x0.8

From equation (3.5) $T = \frac{F_t * d}{2} = \frac{2560*4.6}{2} = 5888\ [Nmm]$

Where T is torque in [Nmm], d is the middle diameter of hole in [mm], F_t is the tangential force in [N].

Power Calculation for tapping of M5x0.8

$$P = \frac{F_t * v}{60 * 1000 * \eta}$$

Where P is the power in [KW], F_t is the tangential force in [N], v is the velocity in [m/min.] and η = 0.8 is the motor efficiency.
And I get:

$$P = \frac{2560 * 6.6}{60 * 1000 * 0.8} = 0.352\ [KW]$$

So according to technical data from manufacturer (Elktrim) at appendix motor type will be used in this unit is Sg 71-2A which has the power of 0.37 [KW].

Tapping of the next two holes of M5x0.8 [mm] will be done in the next station using a multispindle tapping head so the power needed for the process is:

$$P_{total} = 2 * 0.352 = 0.704[KW].$$

And so according to manufacturer Elktrim, motor type will be used to tap twice M5x0.8 is also Sg 80-2A which has the power of 0.75 [KW].

Type according ČSN	Ød mm	Product depth[mm]	n[rev/min]	f_r [mm/rev]	P (Mpa) (N/mm^2)	T[N/mm]	quantity	Power [KW]
Drill 08 ČSN 221122	8	15	1900	0.18	1000	1440	1	0.31
Drill 4.2 ČSN 221122	4.2	15	3135	0.1	1000	190.96	1	0.078
Drill 4.2 ČSN 221122	4.2	15	3135	0.1	1000	190.96	2	0.156
Drill 05 ČSN 221122	5	22	3170	0.12	1000	324.76	2	0.27
Taper ČSN223074 M5x0.8	M5	15	500	0.8	1000	5888	1	0.352
Taper ČSN223074 M5x0.8	M5	15	500	0.8	1000	5888	2	0.704

Table 3.3 Cutting conditions versus torque and power

4. Design of basic layout of operations

In general, a machine tool can be subdivided into three groups of parts:

1. The structure, consists of stationary bodies (e.g., beds, columns, portals) and moving bodies (e.g., tables, slides, saddles) that carry out the coordinate motions, as well as moving that carry out the main cutting motion (this is in most instances the spindle), and guideways and bearings that represent the movable joints between moving bodies and stationary bodies. The whole structure must ensure high accuracy of the motions and high rigidity, both static and dynamic, with respect to forces acting on the structure-primarily the cutting forces which were discussed in the previous chapter.

2. The drives, which provide the torque, or force, and speed of motions; taken together these are the power of motions. They can be classified into “main drives” providing the cutting power, and feed drives. They consist of motors and transmissions.

3. Controls, which take care of switching on and off the individual motions in the desired directions, and of controlling their speeds, individually or in a coordinated way so as to shape the path of the tool relative to the work piece.

The drive of the cutting motion is designed as main drive, in distinction from feed drives. It is the drive of a spindle carrying the tool in milling, drilling, and boring. With exception of single purpose machine tools used in mass production, every machine tool is used for a variety of machining operations, requiring the spindle to rotate at various speeds. The required range of spindle speeds and the corresponding torque and power were discussed according to calculation results in chapter three.

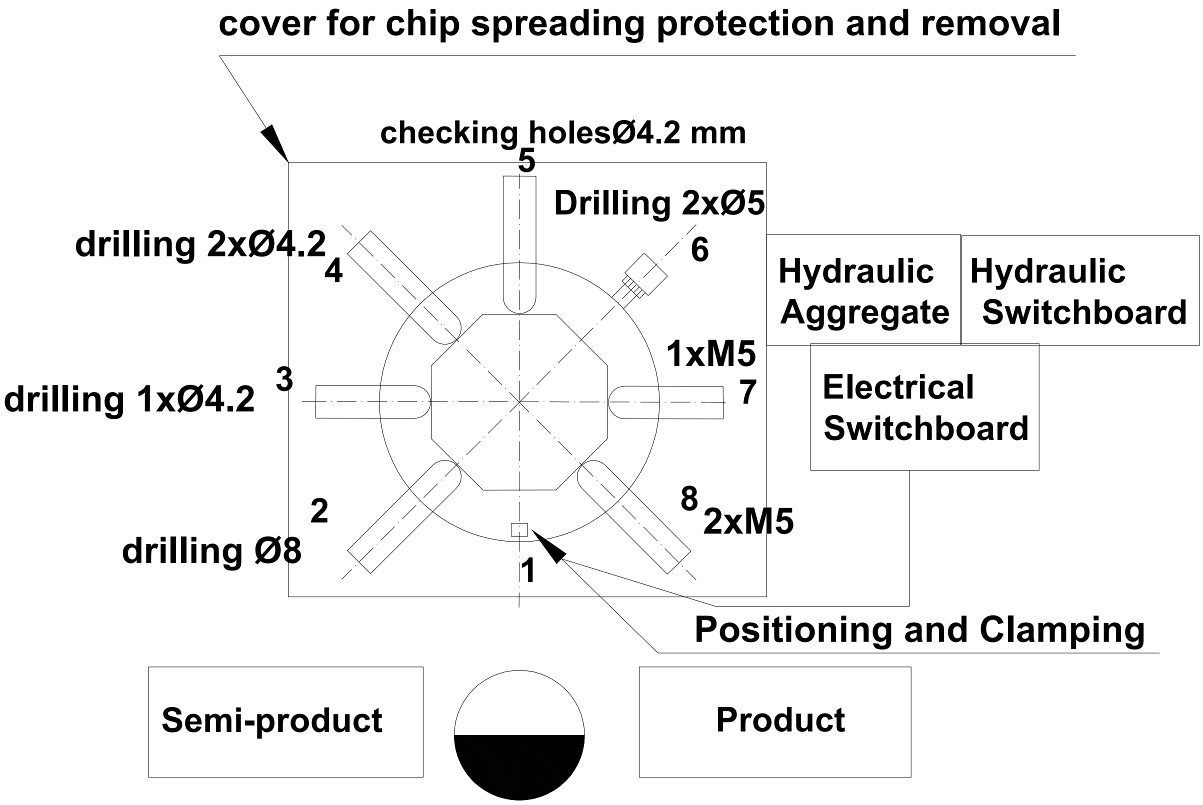

Fig.4.1 Basic layout of operations and working area scheme

The one purpose machine design consists of eight stations and a transport system (Rotary table) carrying the work carriers (jack supports) from station to another station. A mechanical (spring return jack support) is fixed on the rotary table to enable clamping the work piece, Jack support is made of base pad and above it is fixed another pad designed with a hollow according to workpiece dimensions in order to lay it on pad, also there are two extra empty spaces behind workpiece place and under it as well to enable the chip removal. On one side of the workpiece there is a sliding pad with two keyways on its sides. Inside the sliding pad there is a mechanical spring between two pins. It is followed by an eccentric lever. Jack support works by pushing the eccentric lever to achieve clamping workpiece between the sliding pad and the hollowed pad. Also there are enough empty spaces under and behind the product specially designed for allowance of chip removal (section A-A). Jack support is illustrated in the following figure:

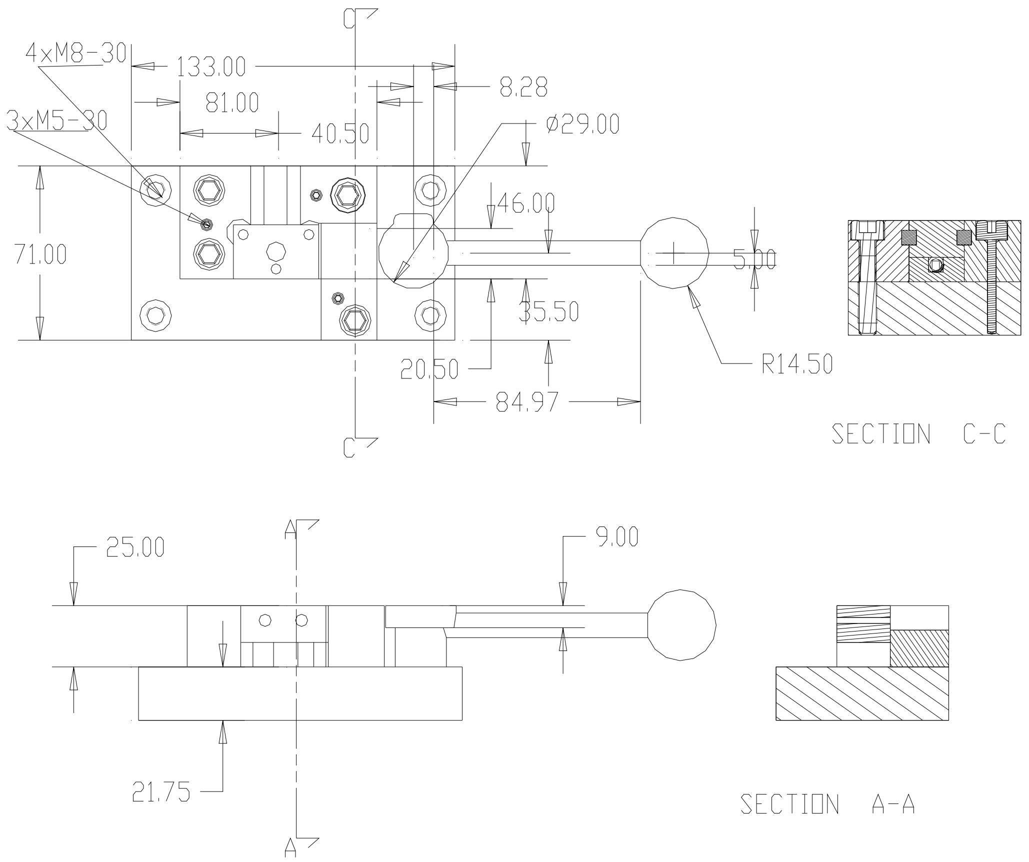

Figure 4.2 Jack Support with product design

Rotary table: the rotating of disk is achieved by built in linear hydro-motor via toothed comb, pinion and drum cam, whose grooves carry the stocks which are closely connected to the rotating table plate.

The arrangement of Locked plates in the exact position is achieved by conical hardened Cape. Locked plate is electrically indicated built-in microswitch which allows automatic or semiautomatic machine function. The Sliding and other moving parts inside the table are automatically lubricated. At the table 500 is the desk swivel base reinforced with body table. Attainment cutting accuracy is approximately 0.05 to stop diameter. This design is illustrated in the following figure:

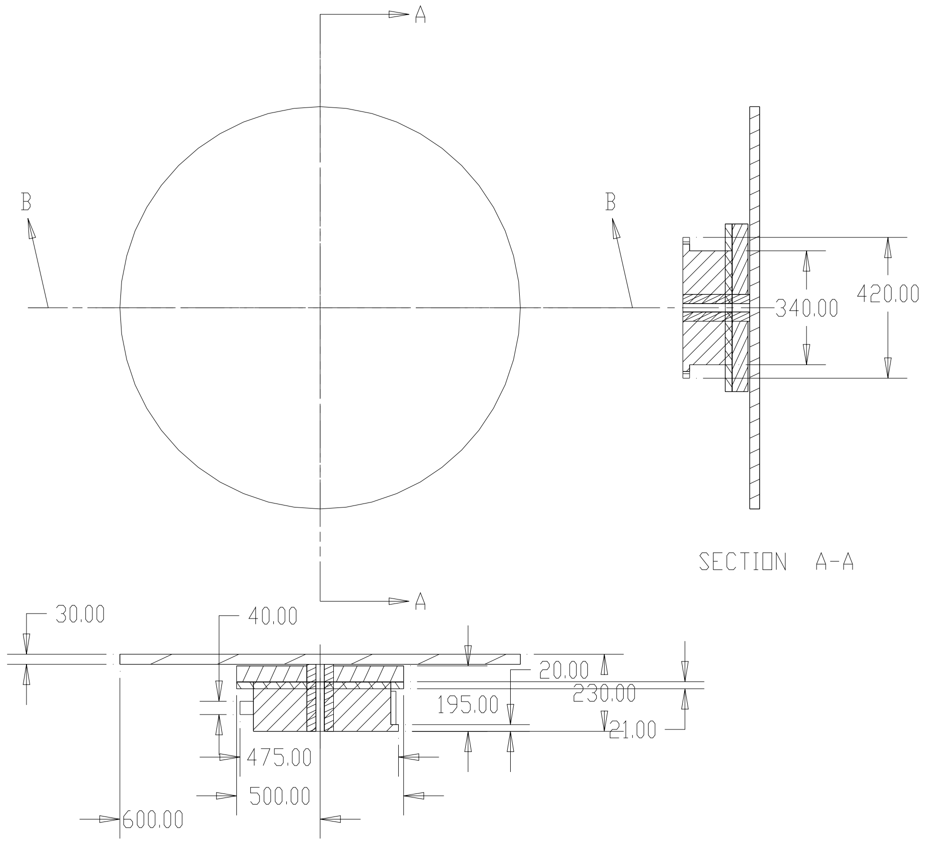

Figure 4.3 Rotary Indexing Table

Rotary table is fixed on an octahedron housing ZK-8, it's sizes and parameters are illustrated in the following figure:

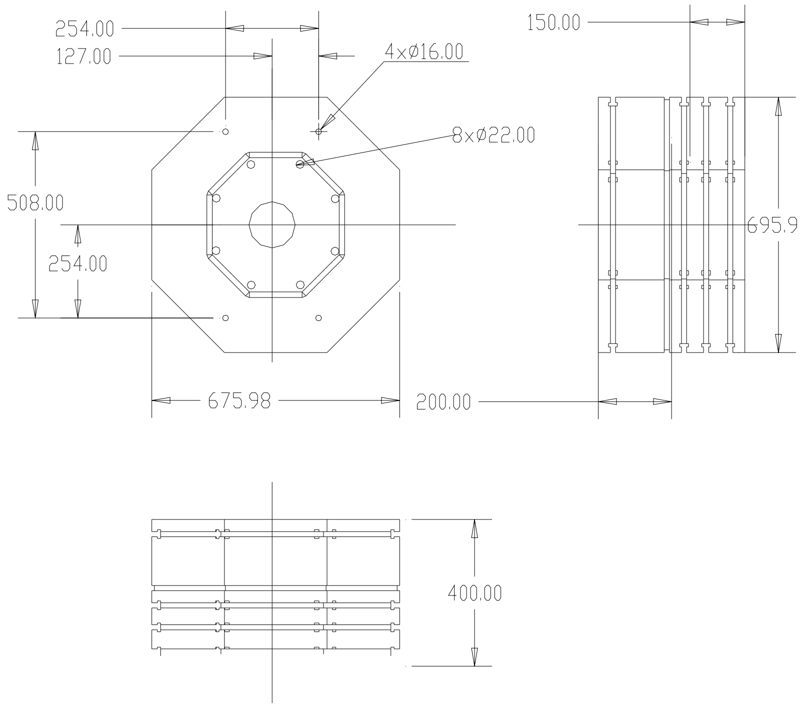

Figure4.4. Housing ZK-8

Housing is mounted above spacer MZK-2, which is illustrated in the figure bellow:

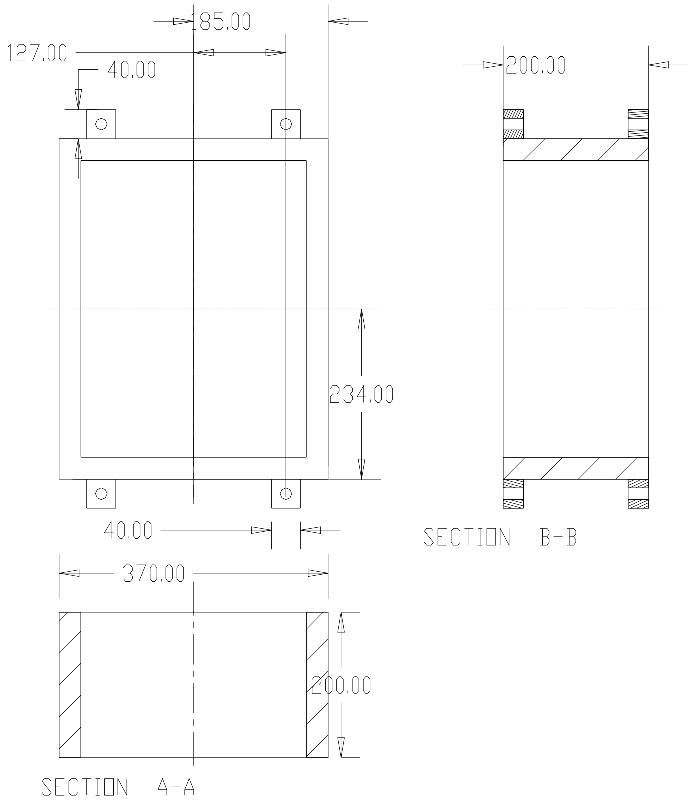

Figure4.5. Spacer MZK-2

Spacer MZK-2 is mounted above a basic table ZS-1 which is illustrated in the following figure:

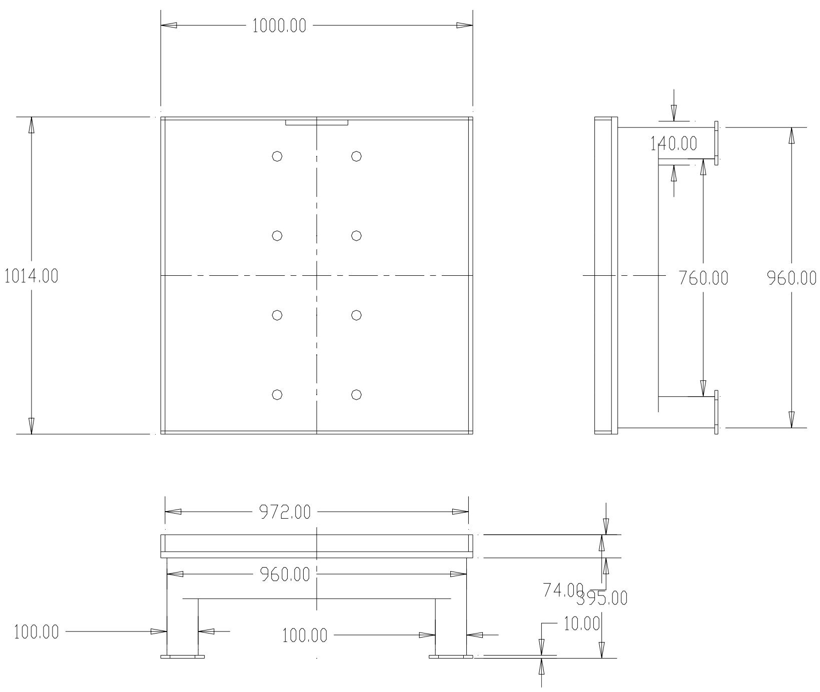

Figure 4.6Basic Table ZS-1

On the sides of the housing ZK-8 are fixed adjustable Consoles KS-1, which is illustrated in the following figure:

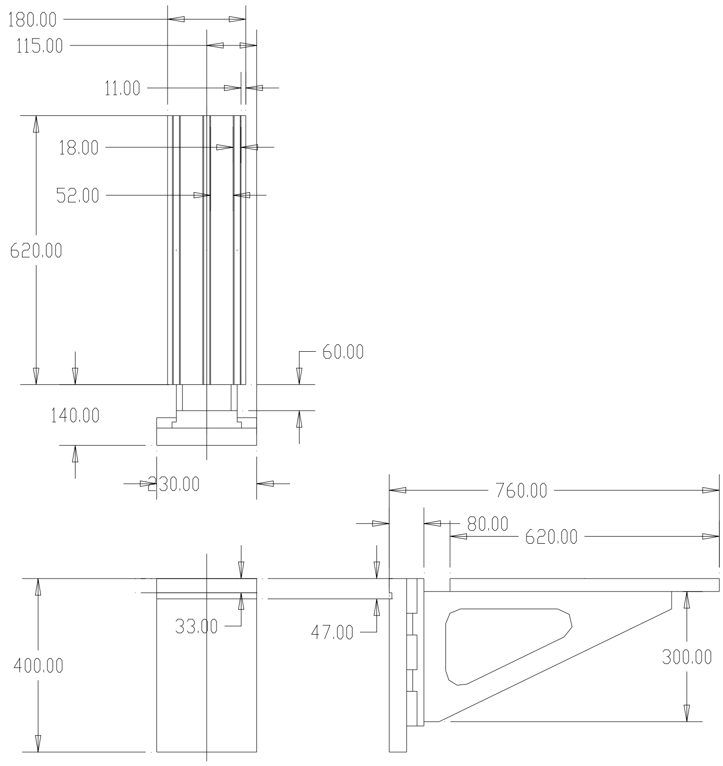

Figure 4.7.Adjustable Console KS-1

On four of the consoles there are fixed pads for accurate construction, shown in the following figure:

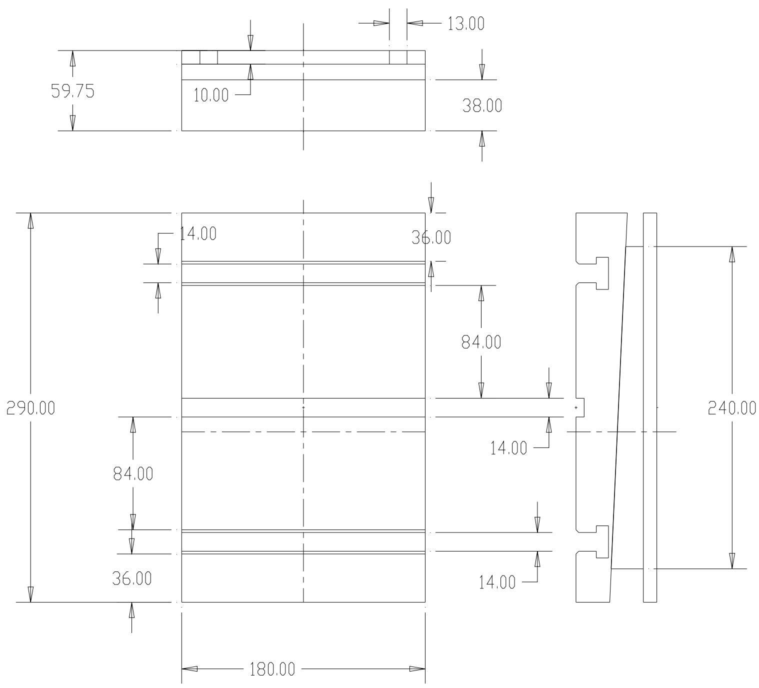

Figure 4.8 Accuracy Pad

On them there are fixed long columns SD-1, shown in the following figure:

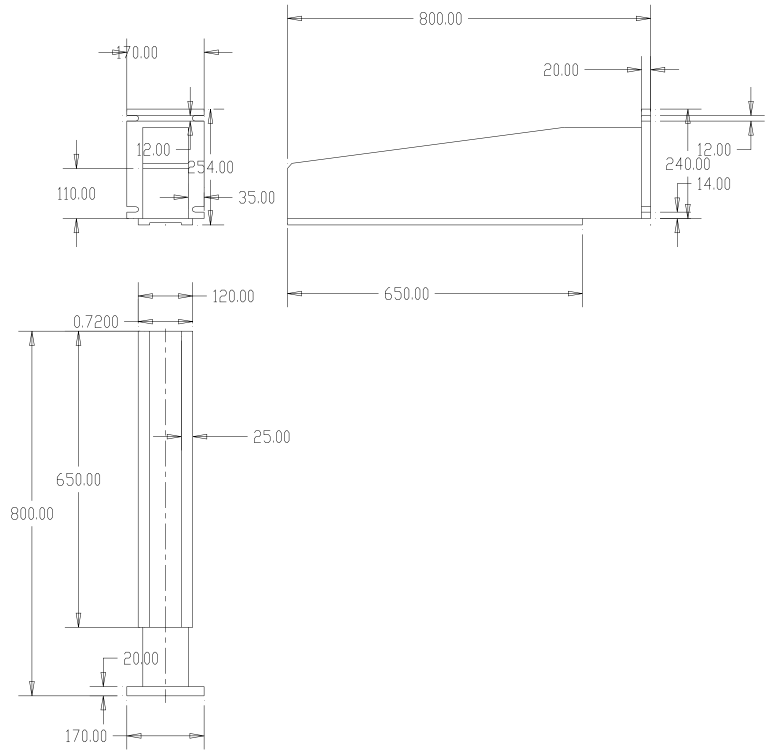

Figure 4.9.Long Column SD-1

On face of long columns are fixed the Movable Sliders SP-1, shown below:

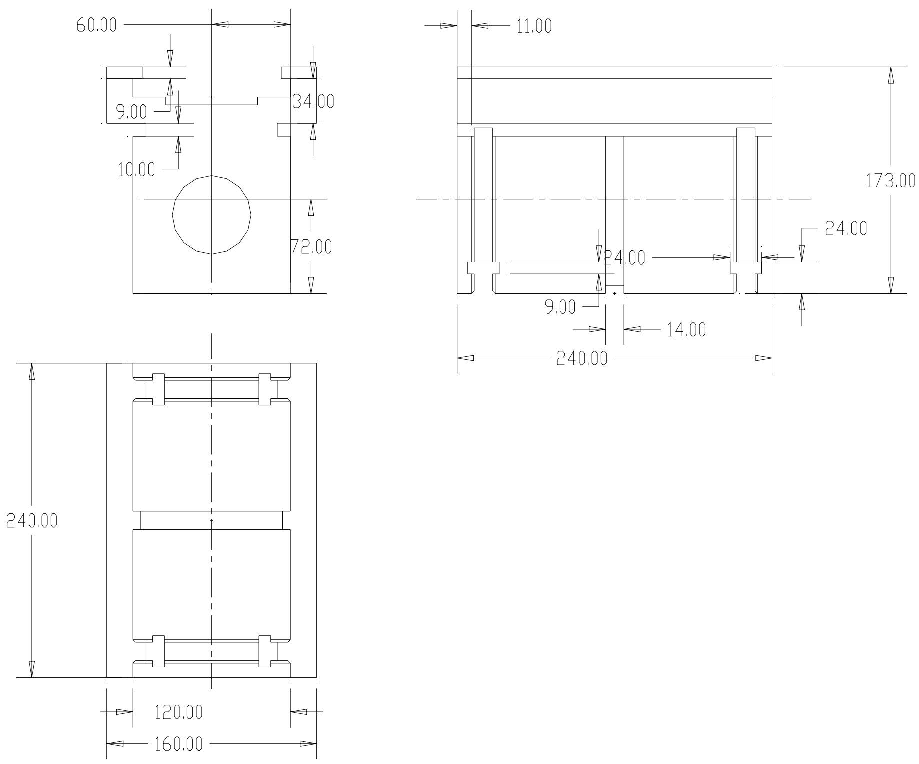

Figure 4.10.Movable Slider SP-1

On the movable sliders are fixed the machining units (hydraulic drilling unit VJHP-10, Tapping unit ZJ 16-100) which are shown in the following figures:

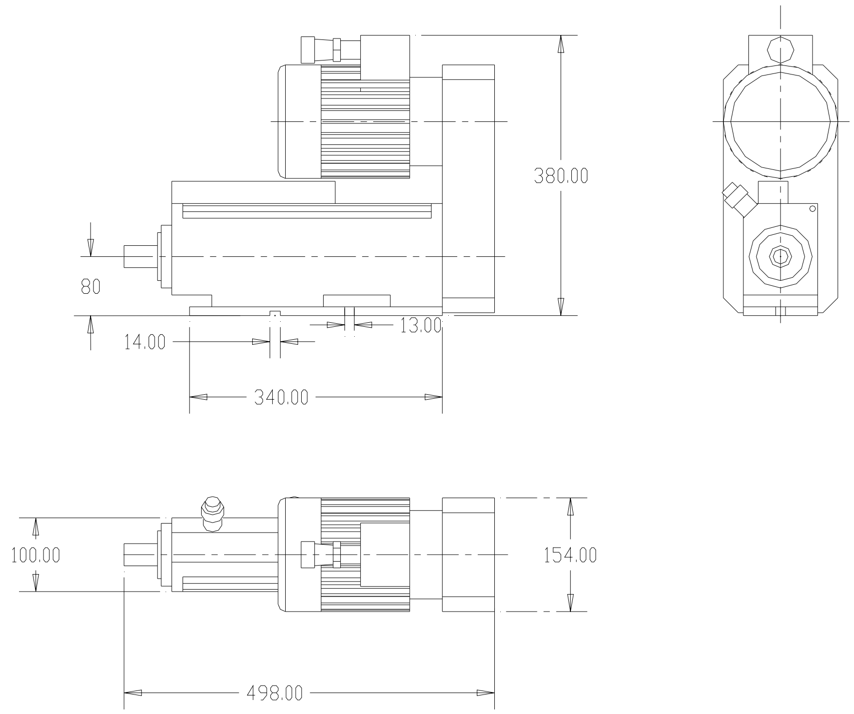

Figure 4.11.Drilling Unit VJHP-10

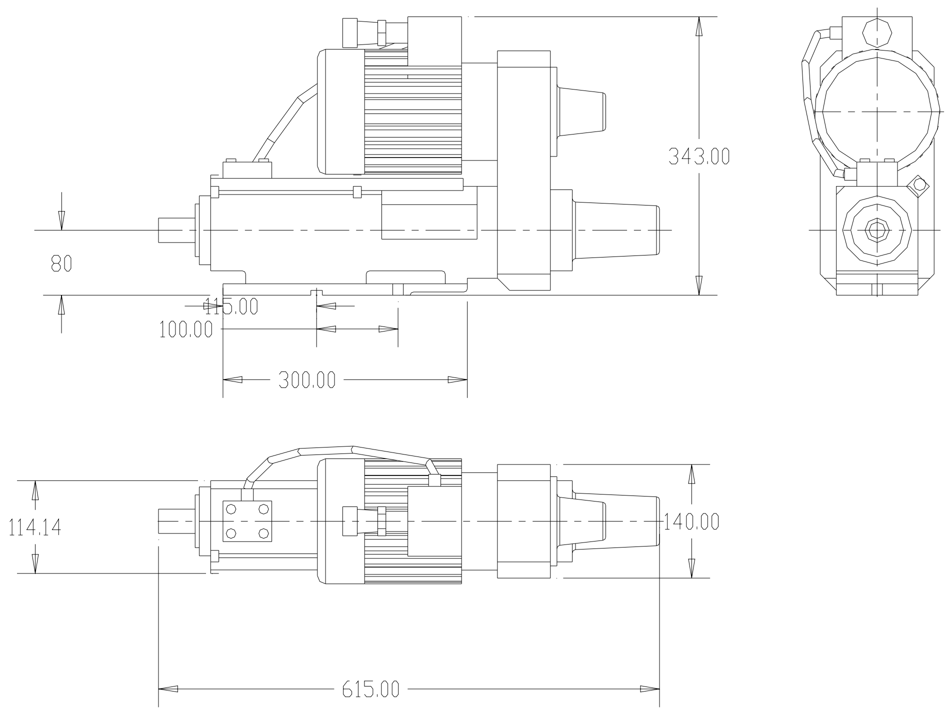

Figure 4.12.Tapping Unit ZJ16-100

Tapping unit is fixed on a symmetrical Pad PS-1, shown below:

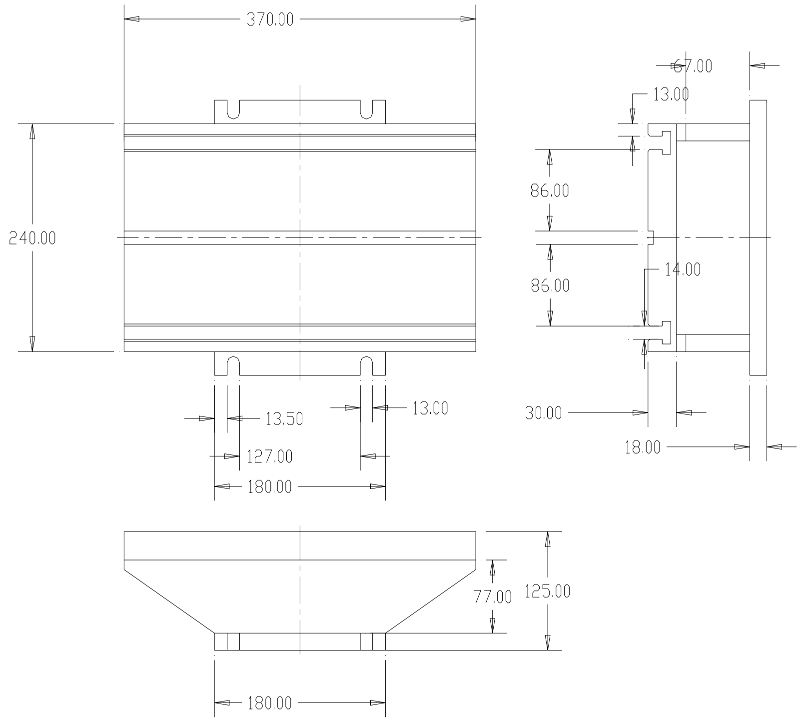

Figure 4.14.Symetrical Pad PS-1

The machine uses stationary work-units (units at positions 2, 3, 4, 5, 6, 7 and 8) for the rotary mechanism (table). The work (jack supports) is moved from station to station, and the motions stops while the different operations drilling at positions 2, 3, 4, 5, and 6 and threading at positions 7 and 8 take place.

4.1. Machine Functionality

The machine is identified for machining of components according to model. Component loading could be done automatically or manually. At place for loading is inserted semi product in to the jack support and held in the jack support. By turning the rotary table workpieces are transferred to individual positions, where the operations are done. After table locking units move directly to workpiece by fast feed, fast feed switch to work feed and when operation are done units will move back by fast feed. When component is back in loading position, product will be unloaded and after cleaning the jack support a new semi-product will be loaded. Machine cycle is half automatic or full automatic and it is remote-controlled by switches from operators place (control panel). Each operation is possible to cancel and units will move back to base position.

4.2. Machine Control

Compact control unit MULTIPOST-1 /mm/: 2480x550x2130 and it contains a hydraulic aggregate, electric-transformer, dividing bridge.

Machine is controlled from operators place, where are located all control elements. Central switch is locking. There is a central switch, hydraulic aggregate, cooling aggregate when individual switches are on, machine will be in standby mode. Pushing button START starts machine cycle. After finishing operations machine is automatically switched to standby mode. On control panel is rotary switch that is used for unit individual control. At position 0 the machine is in half automatic mode, all units working. By switching a rotary switch between different positions: 2, 3, 4, 5, 6, 7 or 8 we can choose only required unit. On positions 1, machine is in full automatic mode -all units are working-, machine cycle time is set on 19 s. Button STOP switch off full automatic mode and it is used together with control individual units. On control panel there is button CENTRAL STOP too. It is for emergency cases. Lights on control panel inform about machine status.

4.3. Machine maintenance

Machine check is every time on start and at the end of shifts, when it is needed to clean the surface of contact and working area and spread these by oil. Chip removal from machine is every time at the end shifts and next according to requirement. Lubricating, oil and cooling emulsion refilling are done once a week.

Machine should be kept clean and it should work in common workshop's temperatures.

4.4. Work accuracy check

Every time at the start of work on machine, it is needed to check the first, the third, the tenth and every next fiftieth machine-made product.

4.5. Work safety

By the machine I need to keep safety regulations according to standard CSN for working machines.

5. Design of fixture and locations

5.1. Design of fixture (Jack support)

In general there are many possibilities to design the semi product fixture.

Mechanical fixture (Jack support) used with high number of pieces production and designed usually according to semi product shape and size.

Here I selected to use a mechanical (spring return jack support) which works by pushing an eccentric lever to clamp semi product, it is illustrated in figure 5.1 and also technical drawing of it is attached on appendix 04.

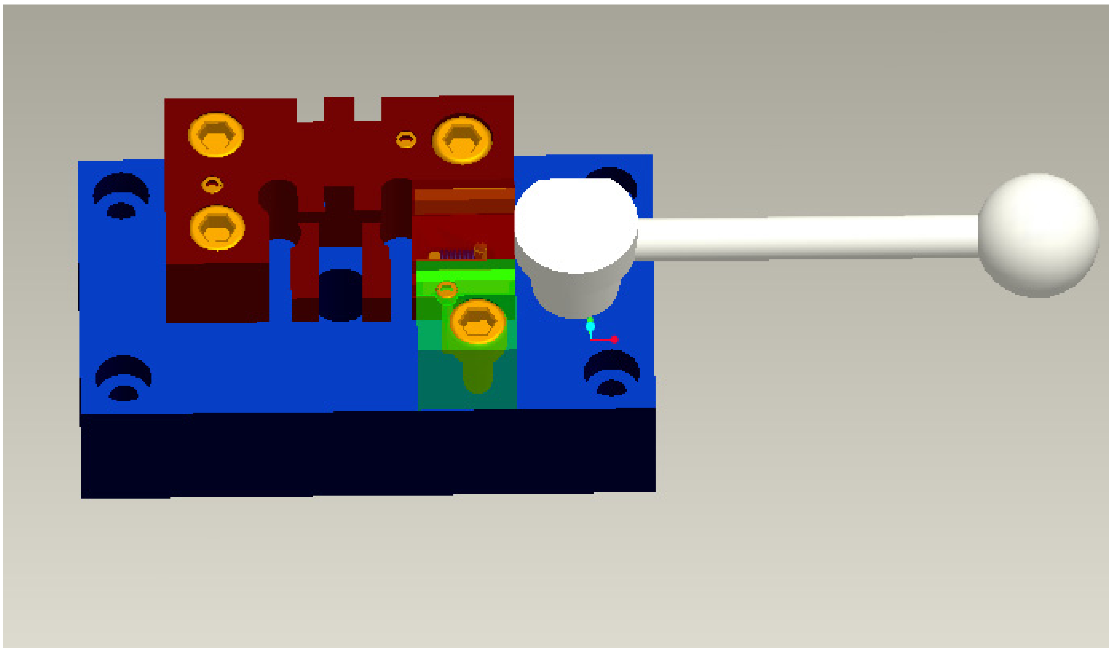

Fig.5.1 Jack Support Design

5.2. Locations of Fixtures (Jack supports)

The jack supports are fixed on the rotary table in all the eight positions of machining units places, they are mounted there in the way which enables the labor to clamp semi product and load and unload it from position of clamping (position 1). See the following Figure:

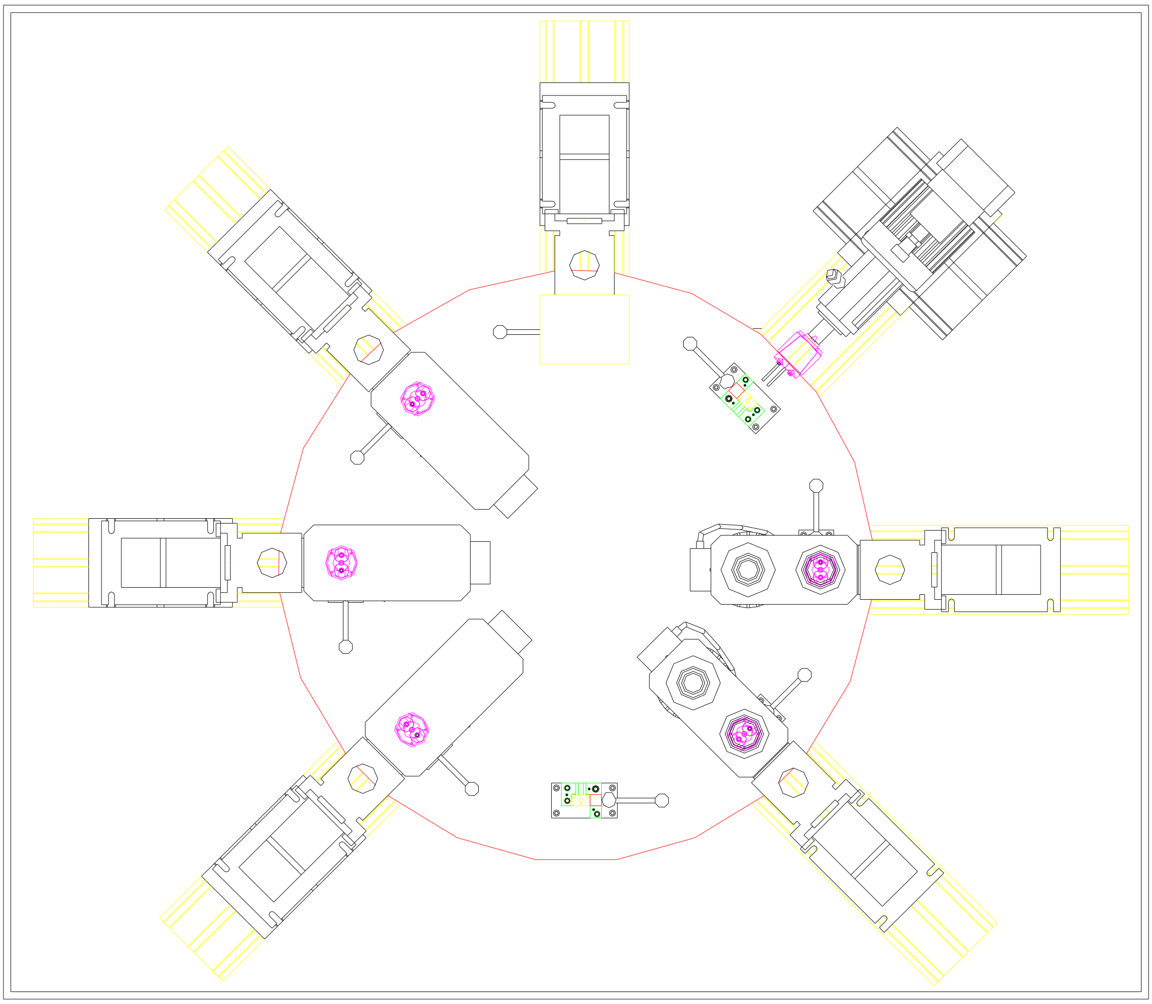

Fig.5.2. Jack support positions on table

6. Selection and assembling modules from catalogue

6.1. Machine configuration design

Complete machine assembly is from available modular units according to Catalogue "MULTIPOST kit component ʼʼ, which is used under construction of Pro-engineer wildfire 4.0.in order to designate the machine assembly.

Substructure consists of a base table ZS-1 for positioning service space in vertical direction a step-up spacer MZK-2 is used, which is mounted on a octahedron base block (housing)ZK-8. On the base block sides are seven adjustable consoles KS-1 with the machining units four hydraulic drilling units VJHP-10 with different electrical motors, and drilling unit is able to work in a mode of a single spindle drill head or a multi-spindle drill head mode at positions three and five. Tapping units ZJ 16-100 are at positions six and seven. Tapping unit ZJ 16-100 at position seven has a Multi spindle tapping head. All drilling units are placed on accuracy pads. Jack support is located on a hydraulic rotary table of type EKDY -500 which is assembled on the polygon base block (housing). For driving of motion mechanisms a hydraulic aggregate is used. Cooling aggregate is engaged under the base table.
The next accessory is an electro distribution transformer. These are illustrated all in the following Figures 6.1.and 6.2.

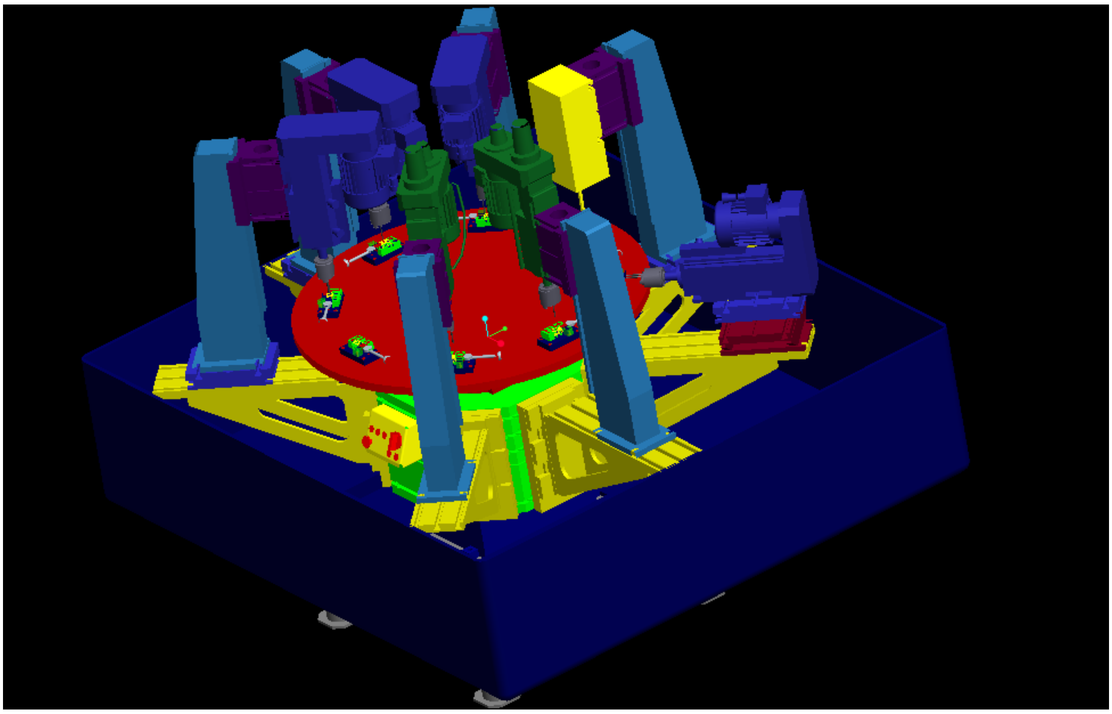

Figure.6.1. Machine configuration design first view

Note: Also see-appendix for detailed technical drawing.

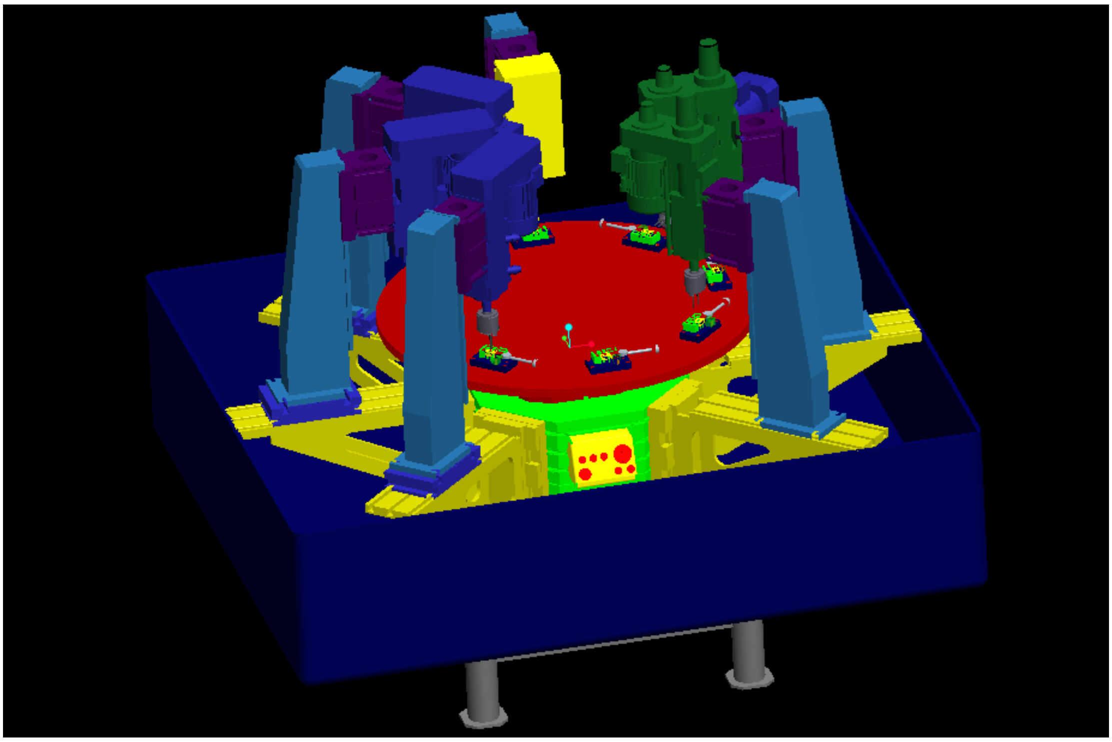

Figure 6.2.Machine configuration design second view

7. Sequence timing

7.1.1. Time of positioning and clamping work-piece

t_1 = 10 [s] from move table of MTM method for an easy manual movement.

7.1.2. Time of Drilling of Ø 8 [mm]

Drill a hole of Ø 8 up to length of 15 [mm]

Feed f_r = 0.18 [mm/rot.] from table 3.1.

Number of rotations n = 1900 [rot. /min]

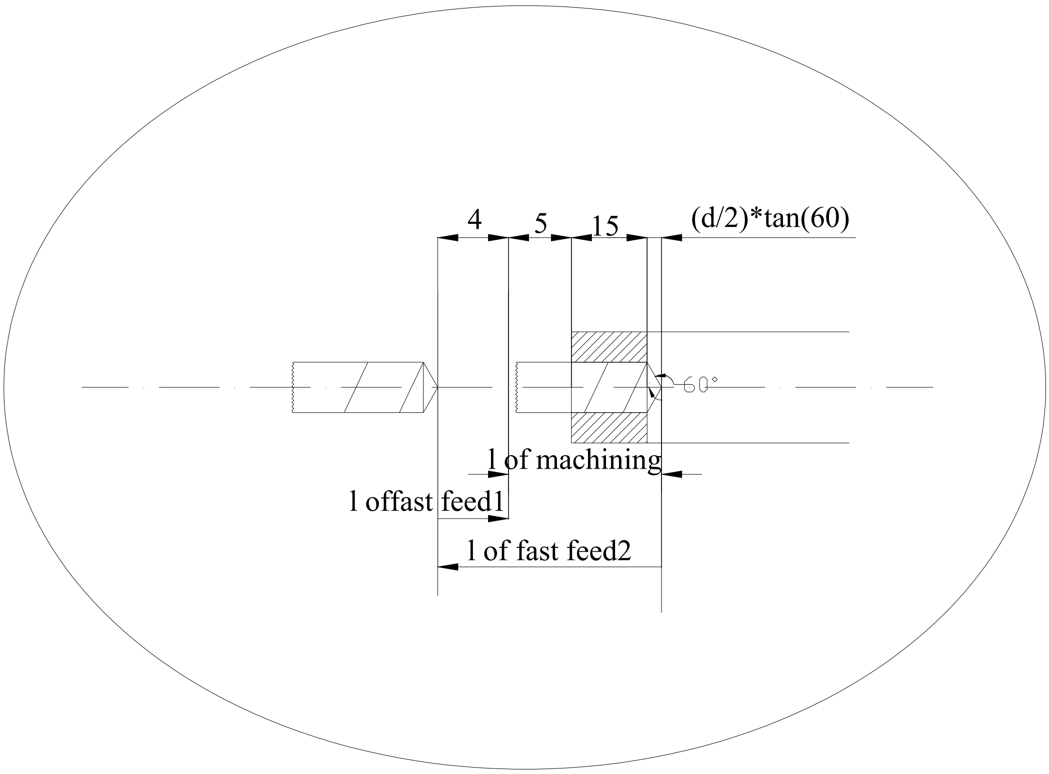

Fig.7.1. Fast feed and machining lengths

Machining time: $t_2 = \frac{l}{n*f_r} = \frac{\left(\left(5+15+\left(\frac{d}{2}\right)*\tan(60)\right)*60\right)}{1900*0.18} = 4.72\ [s]$

Where l is the machining length, f_r is the feed and n is the number of rotations per minute.

Fast Feed length:

$$fast\ feed1 + fast\ feed2 = 4 + \left(5 + 15 + \left(\left(\frac{d}{2}\right) * \tan(60)\right) + 4\right) = 34.93\ [mm]$$

Angular Speed ω = 3000 [s^{-1}] given by manufacturer.

Time of fast feed $t_{ff} = \frac{l_{ff}}{\omega_{ff}} = \frac{34.93*60}{3000} = 0.7[s]$

Total time of machining:

$$t_{total} = t_2 + t_{ff} = 4.72 + 0.7 = 5.42[s] = 0.09[min]$$

7.1.3. Time of Drilling of Ø 4.2 [mm]:

Drill 1x holes of Ø 4.2 up to length of 15 [mm]

Feed f_r = 0.1 [mm/rot.]

Number of rotations n = 3135 [rot. /min]

Machining time: $t_2 = \frac{l}{n*f_r} = \frac{\left(\left(5+15+\left(\frac{d}{2}\right)*\tan(60)\right)*60\right)}{1900*0.18} = 4.52\ [s]$

Fast Feed length:

$$fast\ feed1 + fast\ feed2 = 4 + \left(5 + 15 + \left(\left(\frac{d}{2}\right) * \tan(60)\right) + 4\right) = 31.64\ [mm]$$

Angular Speed ω = 3000 [s^{-1}] given by manufacturer.

Time of fast feed: $t_{ff} = \frac{l_{ff}}{\omega_{ff}} = \frac{31.64*60}{3000} = 0.63[s]$

And total time of machining:

$$t_{total} = t_2 + t_{ff} = 4.52 + 0.63 = 5.83[s] = 0.097[min]$$

Time of the next two operations of drilling Ø 4.2 [mm] will be same to this result.

7.1.4. Time of Drilling of twice Ø 5 [mm]

Drill 2x holes of Ø 5 up to length of 22 [mm]

Feed f_r = 0.12 [mm/rot.]

Number of rotations n = 3170 [rot. /min]

Machining time: $t_2 = \frac{l}{n*f_r} = \frac{\left(\left(5+22+\left(\frac{d}{2}\right)*\tan(60)\right)*60\right)}{3170*0.12} = 4.94\ [s]$

Fast feed length:

$$fast\ feed1 + fast\ feed2 = 15 + \left(5 + 22 + \left(\left(\frac{d}{2}\right) * \tan(60)\right) + 15\right) = 61.33\ [mm]$$

Angular Speed$_{ff}$ ω_{ff} = 3000 [s^{-1}] given by manufacturer.

Machining time of fast feed: $t_{ff} = \frac{l_{ff}}{\omega_{ff}} = \frac{61.33*60}{3000} = 1.23[s]$

Total time of machining:

$$t_{total} = t_2 + t_{ff} = 4.94 + 1.23 = 6.17[s] = 0.102[min]$$

7.1.5. Time of tapping M5x0.8

Cut thread M5 at length of 15 mm.

Feed f_r = 0.8 [mm/rot.] from table 3.1.

Number of rotations n = 500 [rot. /min]

Machining time: $t_2 = \frac{l}{n*f_r} = \frac{(5+15)*60}{500*0.8} = 3\ [s]$

Fast Feed length:

$$fast\ feed1 + fast\ feed2 = 15 + (5 + 15) = 35\ [mm]$$

Angular Speed ω = 3000 [mm/rot.] given by the manufacturer.

Time of fast feed: $t_{ff} = \frac{l_{ff}}{\omega_{ff}} = \frac{35*60}{3000} = 0.7[s]$

Total time of machining:

$$t_{total} = t_2 + t_{ff} = 3 + 0.7 = 3.7[s] = 0.061[min]$$

Time of the next tapping process is the same as this result.

7.1.6. Overall time Calculations

Unit	Holes machined	Total process time [s]
Drilling unit 1	Ø 8 [mm]	5.42
Drilling unit 2	Ø 4.2 [mm]	5.83
Drilling unit 3	2xØ 4.2 [mm]	5.83
Checking unit	Only checking 3xØ4.2[mm]	3.7 [estimated]
Drilling unit 5	2xØ 5 [mm]	6.17
Tapping unit 1	M5x0.8	3.7
Tapping unit 2	2xM5x0.8	3.7
table rotation time		1*8= 8

Table 7.1.Machining Processes time

Because all operations start at the same time so time of the longest operation added to table rotation time will be considered as the machine cycle time.

Drilling of 2xØ 5 [mm] 6.17 [s] the longest operation time

Table rotations 8 [s], $\frac{60}{8} = 7.5\ [rpm]$

Machine cycle Time: $6.17 + 8 = 14.17 = 0.236[min]$

7.2. Machine productivity

Machine produces number of pieces: $\frac{60}{0.236} * 0.8 = 203$ [piece/hrs] where 0.8 is the efficiency.

7.3. Economical analysis

During one working shift number of pieces is: $7.5 * 203 = 1522[piece]$

Number of pieces produced per one day is 1522 [piece]

During one year there are 52 weeks, each week is having 2 days as a weekend so:

$$365 - (52 * 2) = 261[day]$$

Subtracting days of maintenance $261 - 20 = 241[day]$

So working days number is 241 [day]

During one year using one machine at one working shift with the efficiency of 80 % we get production number of: $241 * 1522 = 366802[piece]$

Number of pieces per year is 366802 [piece]

Machine life time is 4 years, so the minimum machining costs per piece should be calculated as follows:

$$\frac{machine\ price}{number\ of\ pieces\ per\ machine\ life\ time} - \frac{2701000}{4 * 366802} = 1.84[Kč]$$

7.4. Assessment of total costs:

Pos.	Name-Dimensions	Q.	Price/Piece [CZK]	Total Price [CZK]
1.	Base Table ZS-1	1	7000.00	7000.00
2.	Spacer MZK-2	1	5000.00	5000.00
3.	Octagonal Housing ZK-8	1	20000.00	20000 .00
4.	Adjustable Console KS-1	7	15000.00	1050000.00
5.	Long Column SD-1	6	12000.00	72000.00
6.	Movable Slider SP-1	7	12000.00	84000.00
7.	Symmetrical pad PS-1	1	10000.00	10000.00
8.	Accuracy pad	5	10000.00	50000.00
9.	Clamping desk (J.S.)	8	1000.00	8000.00
10.	Hydraulic rotary table EKDY-500	1	60000.00	60000.00
11.	Hydraulic Drilling Unit VJHP-10	5	120000	600000.00
12.	Tapping Unit ZJ 16-100	2	120000	240000.00
13.	Cooling aggregate CH-2	1	25000.00	25000.00
14.	Cover	1	25000.00	25000.00
15.	Electrical switchboard	1	40000.00	40000.00
16.	Hydraulic switchboard	1	50000.00	50000.00
17.	Hydraulic aggregate	1	35000.00	35000.00
18.	Palette for semi-products and products	2	5000.00	10000.00
19.	Container for removed chips	1	20000.00	20000.00
20.	Working place equipment	1	50000.00	50000.00
21.	Multispindle head MH 203	6	40000.00	240000.00
Price of one Machine		**2701000.00 [CZK]**		

Table 7.2 Machine components with price

7.5. Technical economic audit

1.	Machine serial number	MULTIPOST
2.	Consumer - User	KVS work shop
3.	Component – name, Trade mark	Complex part KVS™
4.	Year of Production	2010
5.	Variant	Single-Purpose Machine
6.	One Piece Production Time [min]	t_n = 0.236 minutes
7.	Coef. Machine employment [min]	V_n = 0.8
8.	Type and number of machines	2x MULTIPOST Type: Single Purpose Machine
		N. of positions: 8
9.	Machine weight total m [t]	m_n =1.2 (t)
10.	Occupied area By Machine A [m^2]	S_n =4.65
11.	Total Power input P_c [kW]	P_{cn} = 1.87
12.	Number of Labors for 3 shifts	$D_n * R_n = t_{1n}$ =2*3= 6
13.	Machine Price [CZK]	C_n = 2701000.00
14.	Wage cost per day M [CZK/day]	[CZK/hrs] *overhead cost * t_{1n} = M_n 50 * 8 * 3 = 1200
15.	Amortization per year totally R_n [CZK]	C_n * alpha = R_n 2701000.00 * 0.2 = 540200
16.	Machine Rate S_s [CZK/hrs]	R_k / 3600.00 = S_{sn} 540200 /3600.00 * 0.5 = 300.11
17.	Total Rate per hour S [CZK/hrs]	$M_n + S_{sn} = S_n$ 1200 + 300.11= 1500.11
18.	Machine Power per hour P [pieces/hrs]	60/ t_n = P_n 60/ 0.236 =254
19.	Piece cost N [CZK/hrs]	S_n / P_n = N_n 1500.11/ 254 = 5.90

Table 7.3.Economical audit

alpha = 0.2 (amortization coefficient)

Number of Labors per one Working-shift is D_n

Number of Working-shifts is R_n

7.6. Conclusions

1.Required number of pieces is 2000000.00 [piece], So 2 machines at 3 working shifts per day with the efficiency of 72.5 % should be used in order to get required number of 2000000.00 [piece]. And it is calculated as follows:

$$pieces\ per\ hour * working\ hours\ per\ shift * \ machines\ used * shifts\ per\ day * \ working\ days\ per\ year * efficiency = 2000000.00[piece/year]$$

$$= \frac{60}{0.236} * 7.5 * 2 * 3 ** 241 * 0.725 = 2000000.00[piece]$$

2. Another solution to achieve the required number of pieces is to reduce total machining time of one product.

3. One advantage of the single purpose machine is that it is so sufficient for such high number of production.

4. Also in this project full automation could be achieved by making the process of inserting the raw part into the jack support automated; that could be done using a cartridge full of raw parts enough for one shift for instance.