TECHNICAL UNIVERSITY IN LIBEREC
Faculty of Mechanical Engineering

DIPLOMA PROJECT

DESIGN OF THE SERVODRIVES FOR THE MANIPULATOR OF THE TECHNOLOGICAL PALLETS

LIBEREC 1995

MOHAMMAD DABDOUB

TECHNICAL UNIVERSITY IN LIBEREC

FACULTY OF MECHANICAL ENGINEERING

DEPARTMENT OF MANUFACTURING SYSTEMS

DESIGN OF THE SERVODRIVES FOR THE MANIPULATOR OF THE TECHNOLOGICAL PALLETS

DIPLOMA PROJECT

Study discipline: (23-19-8) Manufacturing Systems

DMS No. 67

Mohammad DABDOUB

Supervisor: Ing. Jan Skalla, CSc. (DMS, TU in Liberec)

Consultant:

Extent of the Diploma Project

Number of pages: 68

Number of Figures: 30

Number of tabulate: 7

Technical University in Liberec

Faculty of Mechanical Engineering

Department : Manufacturing Systems **School Year :** 1994/1

DIPLOMA PROJECT

Graduate : Mohammad DABDOUB

Study discipline : (23-19-8) Manufacturing Systems

According to the Law Digest No. 172/1990 for the Universities, the Hea the Department of Manufacturing Systems Determines you this Follow Topic for your Diploma Project :

PROJECT HEADDING : Design of the Servodrives for the Manipulator of Technological Pallets.

CONTENT ITEMS :

1. Introduction.
2. State of the Art in the Transport of Workpieces in the FMS.
3. Description of the Manipulator of the Technological Pallets and its Fu ction.
4. Time Analysis of Transporting the Pallets.
5. Design of the Servodrives for the Manipulator Axis X and Y.
   Main parameters:

Traverse Velocity in the X Axis	120 mmi
Maximal Acceleration / Deacceleration	2 ms^{-2}
Maximum Traverse in the X Axis	According to TOS Olomouc information
Maximum Traverse in the Y Axis	
Total Accuracy of Positioning	0.1 mm
Mass of the X Axis (Workpiece Included)	According to TOS Olomouc information
Mass of the Y Axis (Workpiece Included)	
Mass of the Balance Weight of the Y Axis	
Passive Forces in Axis X and Y	600 N
Minimum Position Gain	Kv = 5 sec

6. Conclusions.

Drawings :

Text : 40 pages (figures including)

References :

/1/ HARTLEY, John: FMS at Work. IFS (Publications), UK, 1984
/2/ Description of the Technological Pallets Manipulator for the PVS 400 (FMS in TOS Olomouc)
/3/ Simodrive AC Servodrives for Automation Technology. Siemens, Germany, 1991
/4/ Servodrives (Records of the Lectures)
/5/ Automated Control of the Production Machines (Records of the Lectures)

Supervisor : Ing. Jan Skalla, CSc.

Consultant :

Begining Date : 31.10. 1994

Submission Deadline : 26.5. 1995

Semester : Summer

Doc. Ing. Přemysl Pokorný, CSc.
Department Head

UNIVERZITA V LIBERCI TECHNICKÁ -7-

Prof. Ing. Jaroslav Exner, CSc.
Dean

Liberec 31.10. 1994

Declaration

I declare that I developed my diploma project independently with aid of referred literature under the control of supervisor and consultant.

In Liberec, 20. 5. 1995

....

Signature

The used symbols

a .... acceleration [$m.s^{-2}$]

D .... diameter of rolling pinion [m]

F_T .... passive force [N]

g = ... gravity acceleration [$m.s^{-2}$]

i .... gearing ratio

i_c .... total gearing ratio

I .... moment of inertia [$kg.m^2$]

I_{TOT} ..... total moment of inertia [$kg.m^2$]

I_n .... inertia of motor [$kg.m^2$]

I_{gear} .... inertia of gear box [$kg.m^2$]

I_{ret} ..... reflected moment of inertia [$kg.m^2$]

m .... mass [kg]

M .... torque [N.m]

M_a........ torque acceleration [N.m]

M_d........ torque decceleration [N.m]

M_{max1}..... preliminary value of torque for selection of the motor [N.m]

M_p........ passive torque [N.m]

n_m .... number of revolution of motor [r/min]

ϵ .... angular acceleration [rad/s^2]

t .... time [s]

t_a .... time for acceleration [s]

t_d .... time for decceleration [s]

t_r .... time for ramping acc/decc [s]

t_c .... time for complete exchange [s]

v .... velocity [m/s]

X .... distance of X axis [m]

Y .... distance of Y axis [m]

The travel's speed	(horizontal)	$m.s^{-1}$	2
The lift's speed	(vertical)	$m.s^{-1}$	0,5
The fork's shifting out speed		$m.s^{-1}$	0,25
The microlift's speed		$m.s^{-1}$	0,025
The travel's acceleration	(decceleration)	$m.s^{-2}$	1
The lift's acceleration	(decceleration)	$m.s^{-2}$	0,19

Paths

Repeatable accuracy	mm	± 1
No of addresses in coordinate	x	69
No of addresses in coordinate	y	3
No of addresses in coordinate	z	2
Modulus of the shelf stock's cell	m	1
The minimal permissible distance between measuring labels in coordinate x	mm	400
The minimal permissible distance between measuring labels in coordinate y	mm	400
Length of the shelf manipulator's path	m	78,44
Length of the shed (2 sheds)	m	4,72
The manipulator's stroke	m	2,66
The length of the fork's shifting out	m	0,62

Microlift	$m = 0{,}06$
loading	$m_o = 630$ kg
the manipulator's wcight - mobile part	$m_m = 6200$ kg
the weaght of lifted parts of the manipulator	$m_p = 1018$ kg
the column's weight	$m_c = 1596$ kg
the weight's weight	$m_w = 755$ kg
the lift's weight	$m_e = 815$ kg
the fort drive's weight	$m_{fd} = 210$ kg
the fork's weight	$m_f = 372$ kg
the weight of fork's shiffted parts	$m_{fp} = 100$ kg

CONTENT **Page**

1. INTRODUCTION

1.1 What is FMS

First concept of FMS (Flexible Machining Systems) invented by the Director of R D at Molins, Deptford, London - Theo Wiliamson - planned to use NC (Numerically Controlled) machines to carry out a series of machining operations on a wide range of workpieces. The idea was to make a system combining the flexibility obtained by computer-controlled machines applications with very low manning levels. Workpieces were manually loaded on pallets and then the automatized operations continued:

- movement to the machines
- loading
- tools selection from a magazine added to each machine
- machining workpieces
- clearing swarf
- washing workpieces

This concept with the advent of robots and other computer-controlled equipment can be applied to other processes in any manufacturing industry. The common elements of FMS, computer-controlled machines, sensors and monitors; automated transport with robots and unmanned trolleys and automated warehouses, can be combined into whatever system is needed and such combination gives a prospect of operation for 24h a day, perhaps unmanned at night, instead of usual 15 or 20h.

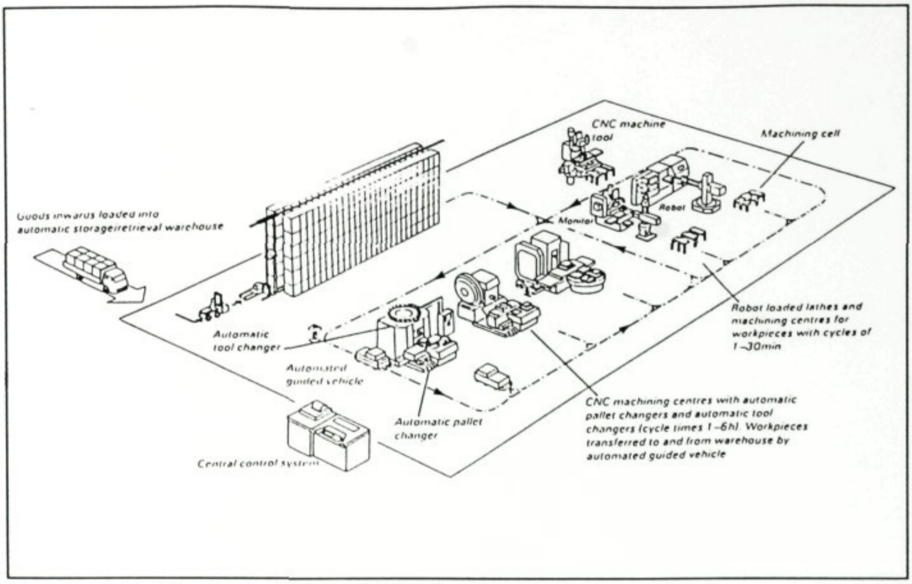


Figure 1.1 The principle of FMS: Machines can work on variety of components unmanned, with automated tool and workpiece changing. Delivery of workpieces by unmanned trolley

Most of the early examples of FMS have been in machine shops based on CNC (Computer Numerical Control) machines but the concept could apply to a robotic assembly line, foundries, press shops, injection moulding shops inspection and test and others. In other words, whatever the process, the question is not whether to turn to an FMS, but how to do it.

1.2 Reasons for FMS applications

What are the advantages of FMS ? Applying FMS into any manufacturing process is the way how to slash drastically the hidden costs

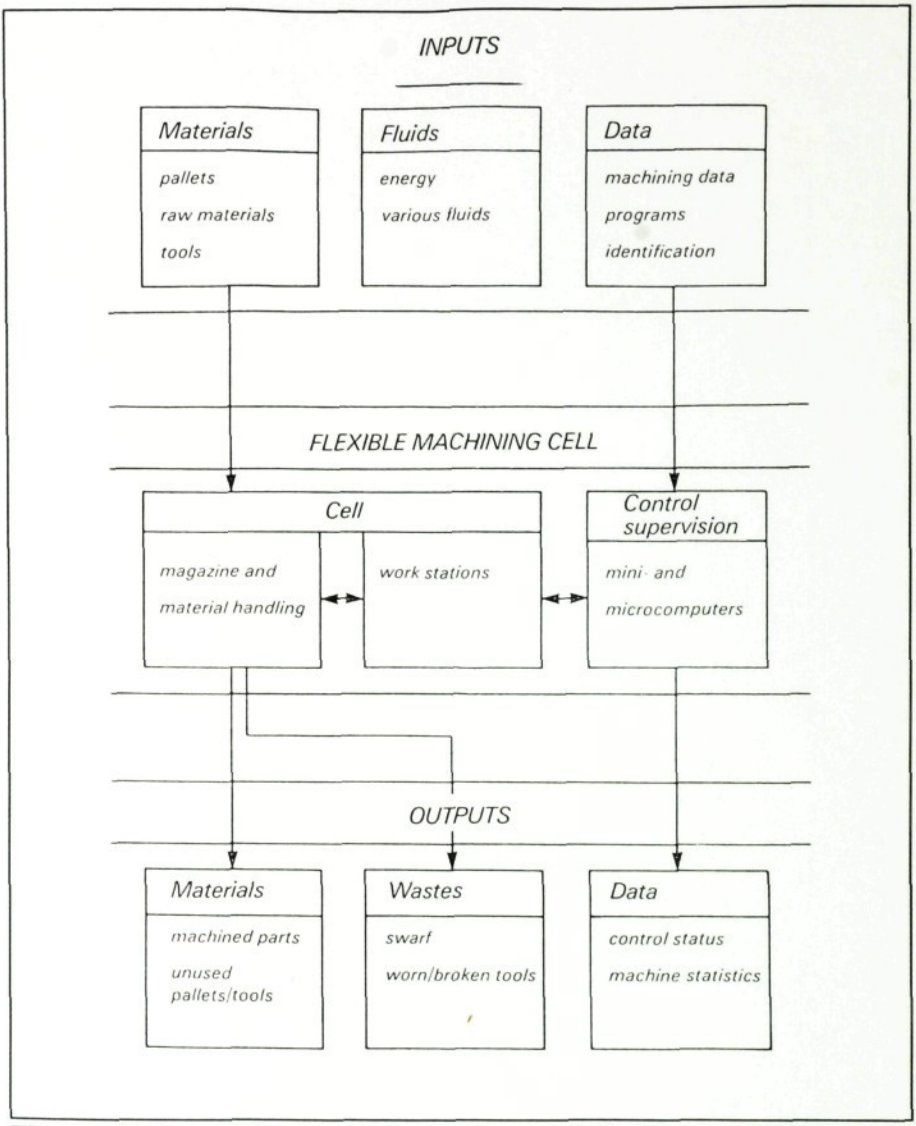


Figure 1.2 General functioning principles of FMS

of manufacture (work-in-progress and overheads such as indirect labour) and thus obtain a high return of company's capital investment.

The research (by Cinnati Milacron) has indicated that on average the

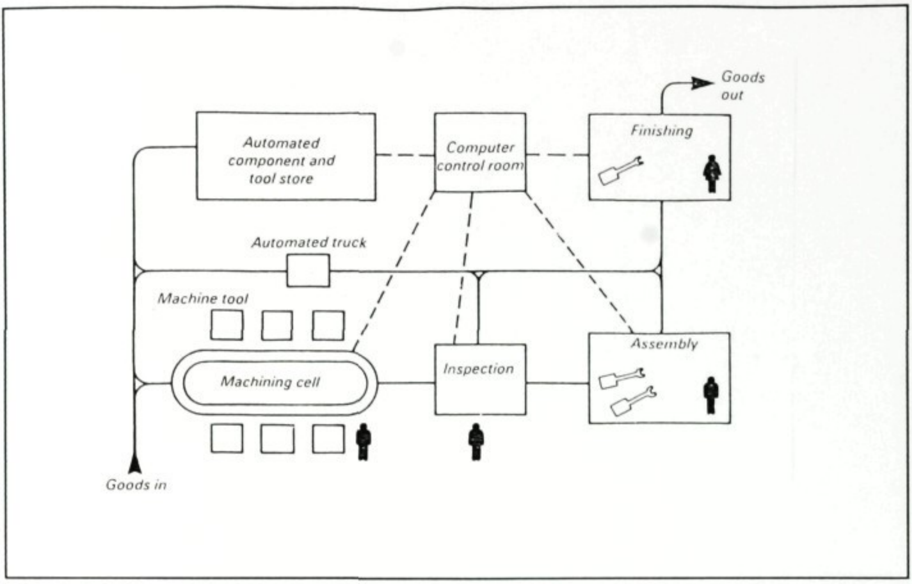


Figure 1.3 Typical layout for an FMS, with machining cell automated truck, computer control, inspection and assembly

workpiece in jobbing machine shops spends on the machine actually about 30% of a working day. The rest of the time is occupied with setting up the machine, obtaining the material for the next job, sorting out, tooling, etc. The cutting itself takes only about 5% of the time in shop.

The machine utilization is rapidly increased with FMS as one CNC machine can carry out a large number of processes with only one setting up.

Another feature of FMS reducing the overheads is the productivity increase brought by extending the working shifts. Usual working day in light industry plants has at present one (manned operation) or two (auto industry) shifts. If there are about 240 working days a year, a plant with two 8-h shifts operates for 3,840 h a year which mean 44% of available time. That time is shortened by breaks (to 41%) and stoppages and machines breaks down at the shop, so that the final time of operation is about 31% of available time.

With FMS the third unmanned shift can be introduced into operation and the potential plant's utilization increases to 98% of available time.

That massive jump in utilization means that the size and costs of the actual plant can be much smaller - less then half the size of the conventional plant. Reducing the size is supported in another way, too. If the work-in-progress can be cut in half, then there is much smaller space for stock and around the shops needed.

Finally, the FMS thanks to it's flexibility meet the customer's requirements as, for instance, short delivery time or quick model changes.

As a difficult point an obvious reducing of the number of people employed can be considered. It's going to be a result of low manning levels and although people may expect that higher productivity will reduce the products prices and so in return increase the demand, this will hardly effect on the reduction of the workforce.

On the other side, the workers skills will necessarily have to be improved in regard to the requirements of computer programming and control, tool and fixture management and maintenance.

The greatest change regarding the workers will however be positive, shortening the working week can reach three days; two days and night, or so. Even some people will perhaps be needed to work some nights or public holidays, those will be only few times a year.

Generally the main features of FMS can be summarized as follows:

1) Reduced plant size

2) Increased machine utilisation, which with (1) and (3) reduce overheads

3) Work in progress reduced by at least half

4) Unmanned operation reducing labour costs

5) Reduced setting-up time

6) Quicker model change

7) Shorter delivery times

8) Consistent accuracy

9) Standardisation of techniques

10) Longer life of capital equipment

11) A route to CAD/CAM

2. STATE OF THE ART IN THE TRANSPORT OF WORKPIECES IN THE FMS

The most suitable devices for supplying the FMS (Flexible Machining Systems) by materials and workpieces as well as for transporting the workpieces between stations are automated guided vehicles (AGV) for their ability to reduce hidden costs. Those costs are caused especially by the excessive stocks as a result of not well controlled amount of work-in-progress, depending more on the operator's speed and efficiency then on the defined lined of assembly; and as a result of higher scrap production from unbalanced machines.

AGVs replace doubtful forklift trucks driven by drivers and they are usually also more suitable then skid tractors (vehicles without forklift systems) and unmanned forklift trucks. The choice of transport according the situation in the plant is mostly between free-ranging AGVs, wire-guided AGVs or rail-guided AGVs and conveyors.

Such transporting system combined from conveyors and AGVs brings the lowest payment of operating costs and investment in compare with other possibilities of combinations, as for example, combination of various kinds of conveyors (monorail/chain, chain/roller) or a conveyor and a forklift.

Even the applications of AGVs vary according to the plant's production program (weight of workpieces), the FMS size and transport requirements, there are some common advantages of AGVs. Automated guided vehicles are suitable for almost any kind of product, they can be rerouted when the plant layout is changed and even a lot of planning and simulation is necessary before installation, it's not so important to start with a small system giving the practical experiences as with FMS. After simulations (setting of: routings, No of trucks, optimized timing, etc) the whole system can be installed all at once or piecwise if preferred.

In compare with conveyors, which are however still proper for small assemblies continuous production of short cycles, AGVs are rather reducing difficulties which can happen with conveyors. Conveyors provide more space for failure, because there are turntables and transfers needed between parallel conveyors so that a lot of working parts are involved. If some of them fail and the conveyor stops, the whole transport system is stopped too. On the other hand with AGVs the majority of the system keeps operation in some case of fail.

While the conveyors keep moving to the next station and don't give a possibility to push through some rush job except bypassing the system with the use of forklift truck, AGVs can move forwards as well as backwards and leave enough space for operator's access to the machines.

Finally, AGVs can load themselves while conveyors need a loader.

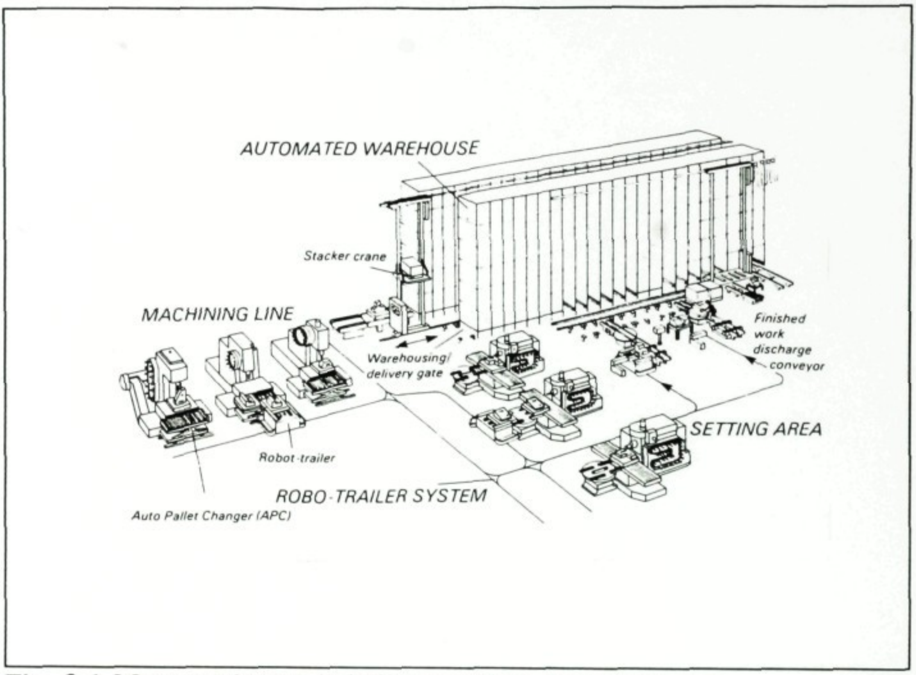


Fig. 2.1 Murata,s layout is built around an asr warehouse

3. DESCRIPTION OF THE MANIPULATOR OF THE TECHNOLOGICAL PALLETS AND ITS FUNCTION

Since the aim of FMS and AGVs introduction is the unmanned operation, let's say the manned operation reducing, the automated forms of the technological pallet's manipulating are desirable.

It's possible to divide the manipulating into two parts:

1) **LOADING / UNLOADING** pallets with workpieces as well as loading and unloading the pallet's carriers by pallets.

2) **TRANSPORT** of pallets between the places of setting up and the machine stations.

The way of pallet's manipulating depends on their arrangement into the carriers and changers. There are three basic kinds of automated pallet's carriers:

- **parallel**, which is one of two twin-pallet APCs common designs and operates in linear movement. It is possible to place at first the new workpiece by AGV at one station and then remove the machined pallet from the other. Two pallets in line can be moved independently.

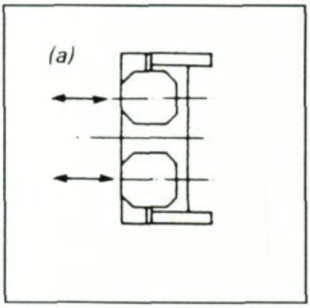


Fig. 3.1 Parallel pallet's carrier

- **rotary**, the other design of twin-pallet APCs. It's larger and less flexible than the parallel type. Before loading a new workpiece to a station, rotary APC must either have a place for two pallets or the machined workpiece must be moved to an empty station.

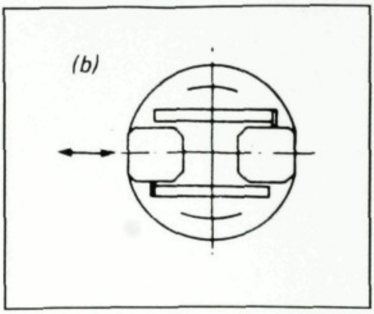


Fig. 3.2 Rotary pallet's carrier

- **multiple**, with four or twelve pallets arranged on circular or oval tables, suitable only for those FMS where the machining cycles are long. When placed between two machines, multiple-pallet carrier may be the proper solution of handling the very large workpieces.

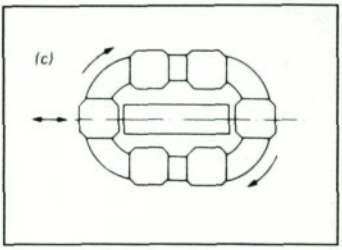


Fig. 3.3 Multiple pallet's carrier

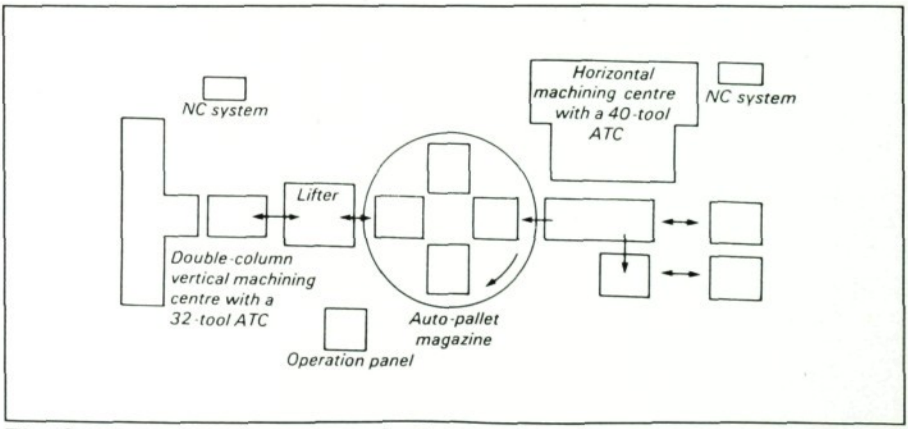


Fig. 3.4 A multiple pallet's carrier between two machines is a neat solution to the handling of very large workpieces

The number of placed pallets, system transferring the pallets between the carrier and the machine and the number of components contained in each pallet influence the period of machining, i.e. the length of the unmanned period. (carriers are loaded by pallets manually).

The mentioned conditions as well as the carrier's arrangement can be modified with regard to each system's individual needs.

The loading / unloading operation is needed to be automated, too. So that for the replacement of a new workpiece from the pallet to the machine and on the contrary the machined workpiece to the pallet are required devices operating continuously and this way reducing the lost time as well as keeping the machining without breaks. The price of the device is also one important point of view. Pallets and machines are loaded by an extension mechanism, rotating arm, double-handed gripper carousel buffer, carousels, robots, gantry cranes and other systems and their combinations. The robot mounted on an AGV which is now under development seems to be the satisfactory solution. It might be able to replace fourteen robots and the gantry crane. Another improvement is possible in automatizing the loading of workpieces on fixtures, which is still mainly the matter of manual work. Application of small robots should reduce the manning, lead time and costs of pallets and fixtures as rather smaller amount of pallets/workpieces will be necessary to store. However even the FMS installation with manual loading/unloading increase the productivity of the plant and reduces it's costs.

3.1. Description of the manipulator

The manipulator is adapted by it's equipment to the following operations:

A) **Automatized** - from the controlling computer through the control system NS 850p

B) **Partly automatized** - from the operator's panel through the control system with the possibility to add the controlling computer which is determined for the running operation's registration only.

C) **Manual (Emergency)** - from the emergency panel. In compare with A and B, this operation's abilities are rather reduced.

Automatized control of the manipulator operates on basis of programmes prepared in advance and no operator's assistance is required while when the operation is **partly automatized** the operator inputs the information for the central control system from his panel.

In case of break down or introduction into operation the manipulator can be controlled by the **manual** control. This kind allows to execute the manipulator's movement in both routs for all three axis. On the other hand the operator has not the detailed information about the manipulator's position (visual only). It's superior to the other two controls.

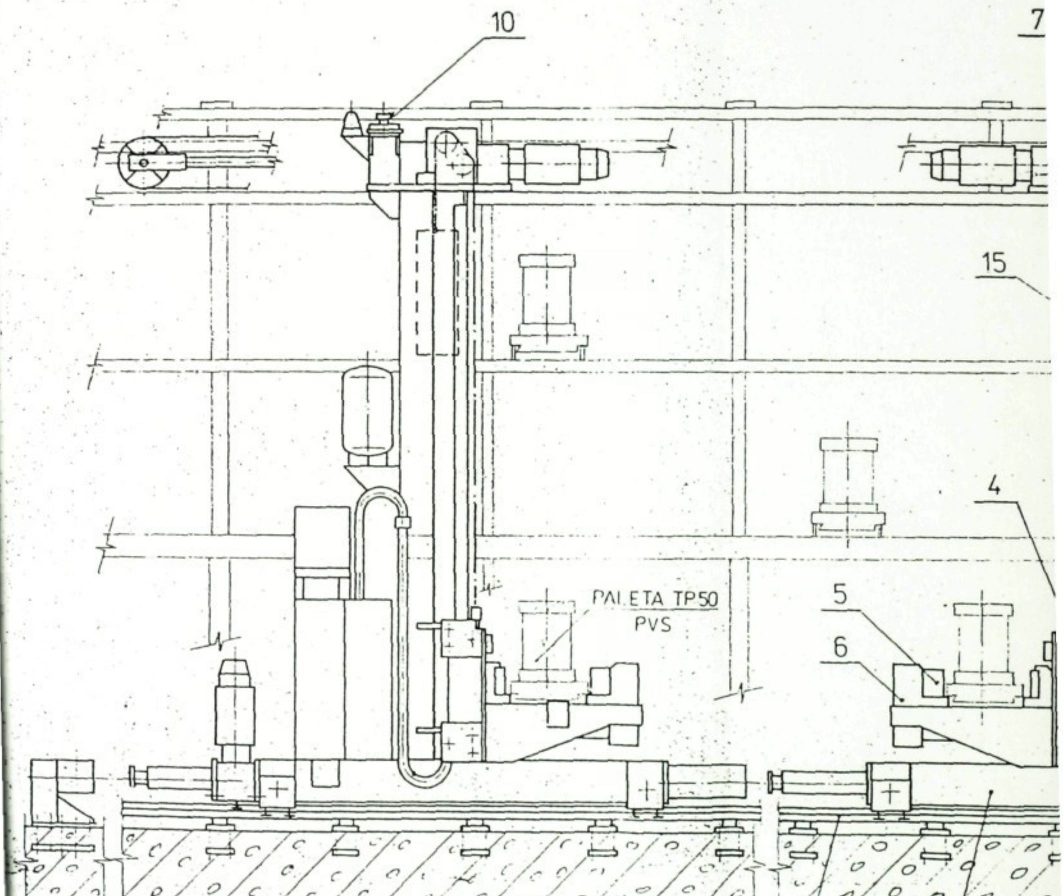
Note: In further description number (x) refers to a number of described part in enclosed drawings 3 3198 0001 and 3 3198 0002.

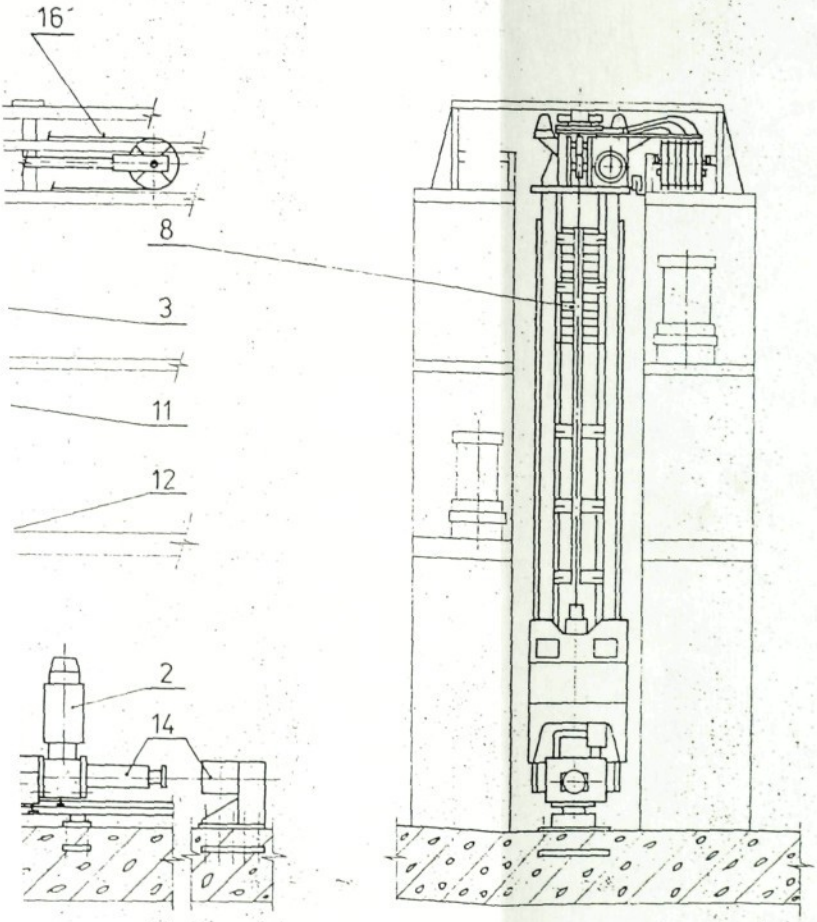
The manipulator's travel buggy (1) moves on the railway with a use of adjustable pulleys. The buggy's side guiding is managed by a system of small adjustable pulleys rolling on the railway's sides. The travel (2) includes a reverse servo-motor Mezomatic and a transmission housing and is firmly connected to the travel's buggy. The travel affords the manipulator's movement on the railway via the gearbox (transmission) with a help of a pinion meshing the rack ridge fixed to the railway (9). The railway with the ridge itself is possible to be adjusted in two directions.

There's a column screwed down to the travel's buggy. The lift (7) which executes the perpendicular movement of the lift's buggy (4) is placed on the column. The lift contains a reverse servo-motor Mezomatic and worm gear transmission. The chain wheel which meshes the double-strand chain is fixed on the output shaft of the transmission. On one side of the chain the lift buggy is fastened through the gripping system on the other side there is a weight (8) guided on pulleys inside the column.

The lift's buggy is guided on the manipulator's column by adjustable pulleys. It's fastened with the carrier. The lift's buggy affords fasting the fork for the technological pallets manipulation. The fork (5) with it's drive (6) is screwed down to the carrier. The drive consists of the reverse non-synchronous motor and the worm gear transmission which drives the cylindrical cam. This drive provides the fork's fluent pushing in and bulling out on both sides with exactly specified length of path.

ig. 3.6



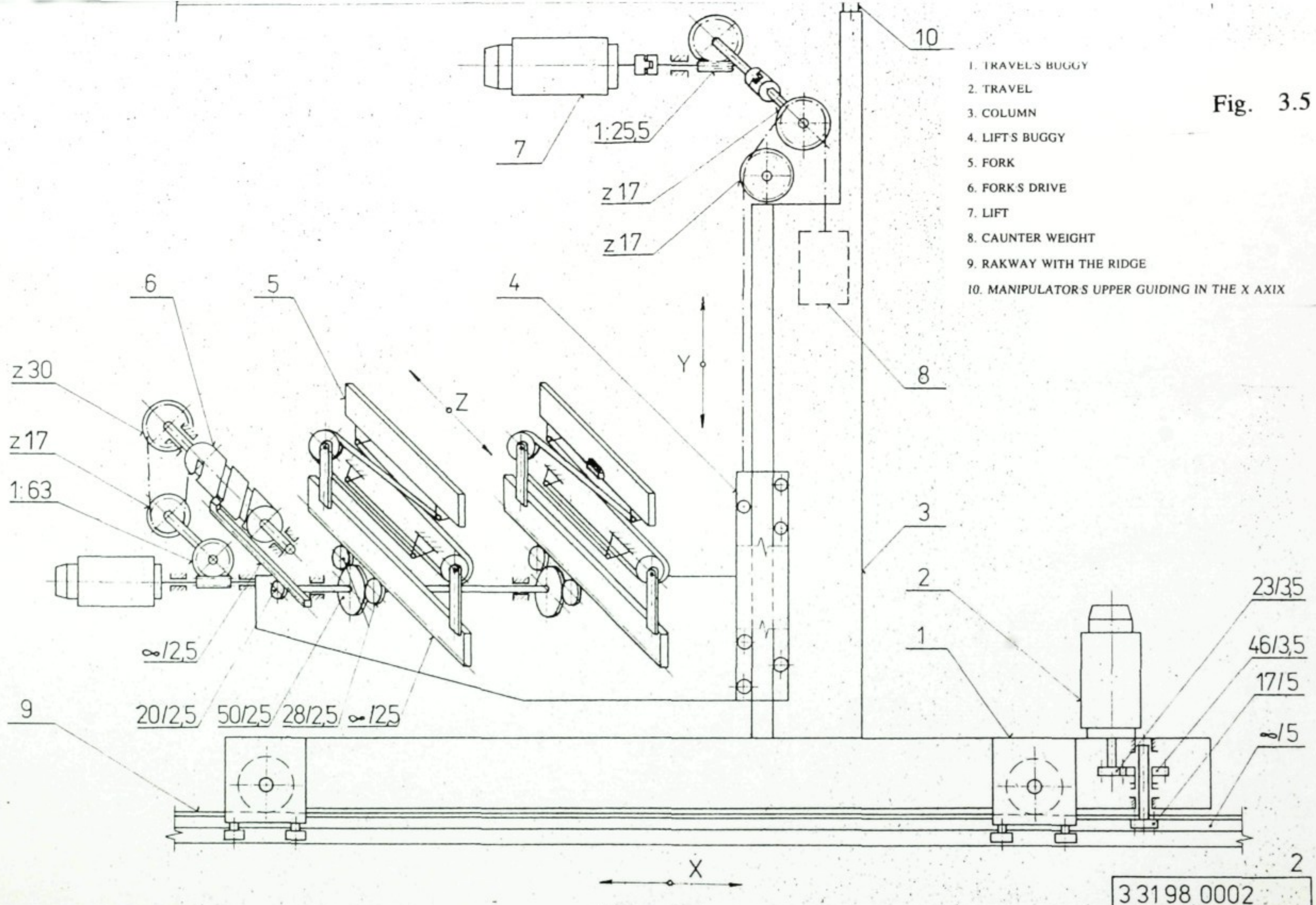


1. TRAVEL'S BUGGY
2. TRAVEL
3. COLUMN
4. LIFT'S BUGGY
5. FORK
6. FORK'S DRIVE
7. LIFT
8. WEIGHT
9. RAKWAY WITH THE RIDGE
10. UPPER GUIDING OF THE MANIPULATOR IN THE X AXIX
11. AIR DISTRIBUTION SYSTEM
12. CONTROL SYSTEM NS 850 P
13. ELECTRICAL MOTOR BOX
14. END STOP (BUFFER)
15. CHAIN 140 CL 20 A2 CSN 023311.0
16. ELECTRITY SOURCE DISTRIBUTION

1

3 3198 0001

Fig. 3.5



1. TRAVEL'S BUGGY
2. TRAVEL
3. COLUMN
4. LIFT'S BUGGY
5. FORK
6. FORK'S DRIVE
7. LIFT
8. CAUNTER WEIGHT
9. RAKWAY WITH THE RIDGE
10. MANIPULATOR'S UPPER GUIDING IN THE X AXIX
10
7
1:25,5
z 17
z 17
8
6
5
4
z 30
z 17
1:63
Y
Z
3
2
23/3,5
1
46/3,5
17/5
∞/5
∞/2,5
9
20/2,5
50/2,5
28/2,5
∞/2,5
X
2
3 31 98 0002

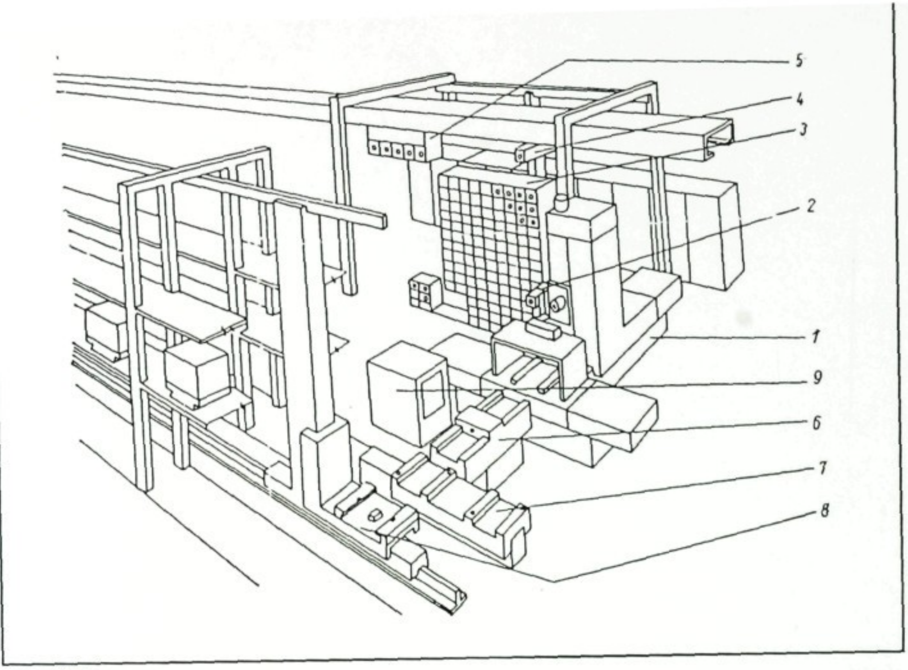


Fig 3.7 Description of a FMS with maipulator of the technological pallets.

1- milling centre

2- exchange station

3- magazine

4- tool manipulator

5- carriage for transport from and to the tool shop

6- pallet exchanger

7- sliding table

8- pallet manipulator

9- washing machine

The manipulator's lane is in the upper part overbridged by the fixed frame. In the centre of the frame along the all travel and travel's buggy the manipulator's upper guiding is fixed - the adjustable railway(10). The pulleys of the lift's upper part roll on that railway.

The air compressor is attached to the column. Obtained air cleaning the photoelectrical head of the pallets code reader. Electrical parts of control, security and further functions are placed in the switchboard firmly screwed down to the travel's buggy. There's a control system **NS 850P** attached to the switchboard. The conjunctions with the controlling computer, control system, emergency control desk and electricity source are done by flat cables in the shelved stock's conduit. The cables are leaded in a way which reduces needless curves during manipulator's movement.

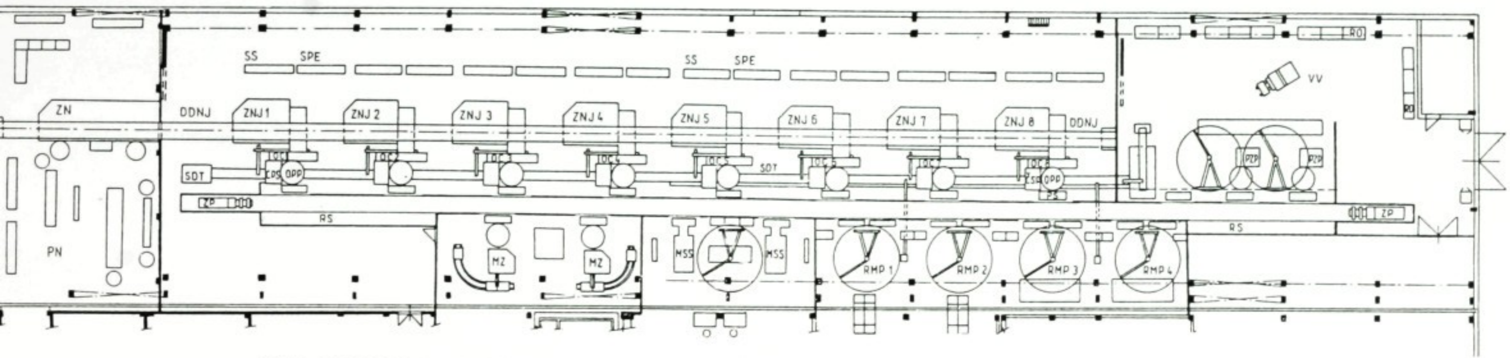
Functional parts are joined by the main distribution system from the switchboard. The rescue control panel is placed out of the manipulator to give a possibility of the manipulator's movement visual control. The schematic drawing of the manipulator with one machining place shows the Fig. 3.7. From the pallet's support places in the shelf stock the horizontal (x) and vertical (y) coordinates system begins. Every support place in coordinates x and y is specified by measuring labels with code numbers placed on:

- the shelf stock: coordinate x (for both right and left sides)
- the manipulator's column: coordinate y

Fig. 3.8 FLEXIBLE MANUFACTURING SYSTEM FOR THE COMPLETE MANUFACTURING OF BOX - WORKPIECES WITH OF THE MAX SIZE 400X400X400 mm

CPS CLEANING STATION
DDNJ TRACK OF THE TOOL UNITS MANIPULATER
MSS COORDINATES MEASURING MACHINE

SS ELECTICAL CAPENEAT
VV FORKLIFT TRUCK
ZN TOOL MAGAZINE
ZNJ TOOL MAGAZINE
ZP PALLET·S MANIPULATOR



RMP MANUAL MANIPULATION
RO SHELFT STORE
RS SHEF STORE
SDT SWARF CONVAIER
SPE ELECTICAL CAPENEAT

MZ WASHING EQUIPMENT
OC MILLING CENTRE
OOP ROTARY PALLET·S CARRIER
PN TOOL·S SHOOP
PZP MEASURING DEVICES FOR PARTLY FINISHED WORKPIECES

The code numbers of measuring labels x and y make an absolute measuring system. It's information supplies photoelectrical readers of x and y measuring plates placed on the manipulator. Distances between the support places needn't be constant but they have to be the basic modulus multiplies. The manipulator's movement control is so called "point-to point". Measuring system is a combination of the direct and indirect measuring. Indirect measuring by the Encoder MIME on the motor shaft is in operation during travelling outside of the target area. Direct measuring is derived from the measuring plates. This measuring plates also contains the code (or address) of the storage cell. In the area of probable target position the speed is automatically slowed down and on the measuring plate the indirect measuring is switched to the direct measuring with the measurement step of 1 mm which secures that the manipulator will stop at the target in the centre of the target's area with the accuracy of $\pm$ 1 mm. The absolute measuring system of measuring plates completes the MIME encoder placed on the Mezomatic drive. To prevent the manipulator's damage in case of break down the control computer's, control system's or position sensor's there is the whole manipulator stopping (in all coordinates) secured by the electrical limit switches. In case of their break down the further manipulator's movement is limited by mechanical end stops (buffers) which are hard or elastic in dependence on the movements energy intensity. When two manipulators are used on the same path then they are secured against their collision by the electrical limit switches and elastic end stops.

3.2. Technical data

Basic technical parameters

Speeds and accelerations

The travel's speed	(horizontal)	$m.s^{-1}$	2
The lift's speed	(vertical)	$m.s^{-1}$	0,5
The fork's shifting out speed		$m.s^{-1}$	0,25
The microlift's speed		$m.s^{-1}$	0,025
The travel's acceleration	(decceleration)	$m.s^{-2}$	1
The lift's acceleration	(decceleration)	$m.s^{-2}$	0,19

Paths

Repeatable accuracy	mm	± 1
No of addresses in coordinate	x	69
No of addresses in coordinate	y	3
No of addresses in coordinate	z	2
Modulus of the shelf stock's cell	m	1
The minimal permissible distance between measuring labels in coordinate x	mm	400
The minimal permissible distance between measuring labels in coordinate y	mm	400
Length of the shelf manipulator's path	m	78,44
Length of the shed (2 sheds)	m	4,72
The manipulator's stroke	m	2,66
The length of the fork's shifting out	m	0,62
Microlift	m	0,06

Weights

Transported material: workpiece with the technological pallet TP 50-PVS

Loading capacity	kg	630
Manipulator's weight - mobile part	kg	6 200
Total manipulator's weight	kg	14 510

Total weight of two manipulators on one path kg 21 270

Drives

Travel's drive: MEZOMATIC 3 SHAT 160 L2 with the continuous torque of 100Nm (which corresponds to 300 min^{-1}), transmission with helical gears i = 2

Lift's drive: MEZOMATIC 3 SHAT 160 L2 with the continuous torque of 100Nm (corresponding to 300 min^{-1}), worm gear transmission VSS Košice i = 25,5

Fork's drive: asynchronous motor 3 APB 90 8-4, power output 1,1 kW, worm gear transmission VSS Košice i = 63

Total power input: about 45 KVA

Safety and the health protection in manipulator's running

The shelf manipulator satisfies all instructions and standards regarding the lifting equipment and respects all paragraphs referring to the shelf manipulators. The manipulator's operation is not placed on the manipulator directly.

3.3. Utilization of shelf manipulators

Utilization of shelf manipulators handling the whole manipulating system according to the year's production.

Table 1. Utilization of the shelf manipulator I.

No	Name	I shift	II shift	III shift
1	Average requirements /shift	164	164	-
2	30% increased No of	213	213	-
3	requirements/ shift	28,9%	28,9%	-
4	I.manipulator's utilization			
	2/3 of requirements No reduced			
	of 5% (the weight of one simple			
	manipulation within the			
	framework of double			-
	manipulation)	205	205	-
5	I.manipulator's utilization	27,76%	27,76%	-
6	Manipulating cycle	0,65min	0,65min	-

Table 2. Utilization of the shelf manipulator II.

No	Name	I shift	II shift	III shift
1	Average requirements /shift	167	167	128
2	30% increased No of requirements/ shift	217	217	166
3	II.manipulator's utilization	29,4%	29,4%	22,5%
4	2/3 of requirements No reduced of 5% (the weight of one simple manipulation within the framework of double manipulation)	209	209	209
5	II.manipulator's utilization	28,3%	28,3%	21,6%
6	Manipulating cycle	0,65min	0,65min	0,65min

Table 3. Utilization of one shelf manipulator handling the whole operating system in accordance to the year's production volume.

No	Name	I shift	II shift	III shift
1	Average No of manipulations increased of 30% and reduced of one simple manipulation's weight, i.e. 5%	205 + 209	205 + 209	160
2	Reduced No of manipulation requirements (27,4% are not taken into use of one manipulator)	301	301	160
3	Average simple manipulation's cycle	0,94min	0,94min	0,94min
4	The manipulator's utilization	58,9%	58,9%	31,3%

Note: Table 3 shows the possibility to use only one manipulator 630 for PVS TOS Olomouc. Use of one manipulator only would bring the following disadvantages:

- In case of manipulator's break down the whole PVS would stop.
- There would not be possible bigger increasing of the manipulating system's operating volume.

Data form the URSST Pieštany research work No 74531 were used in tables working up.

4. TIME ANALYSIS OF TRANSPORTING THE PALLETS

4.1 Calculation of manipulating times of the manipulator's horizontal travelling axes

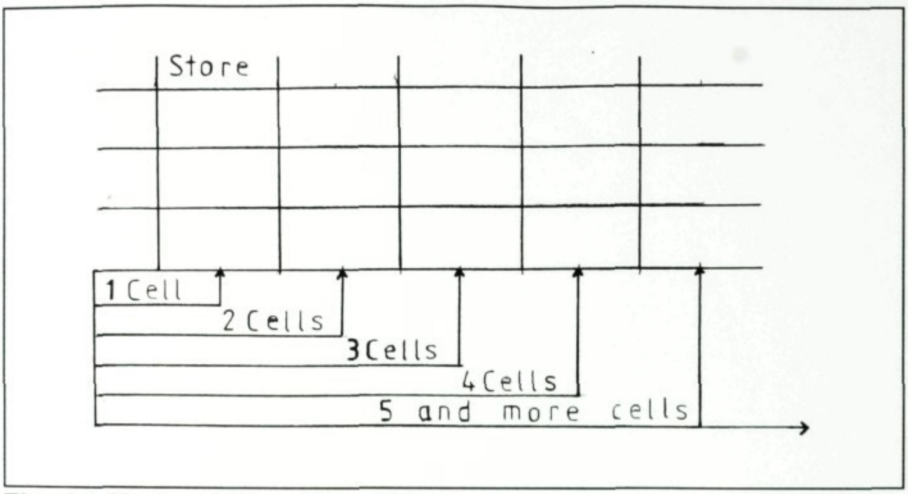


Fig. 4.1 Horizontal travelling distances

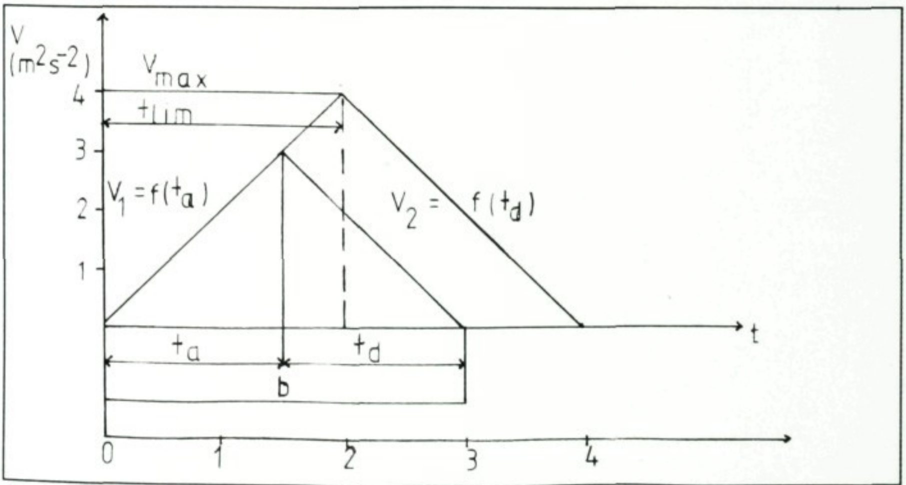


Fig. 4.2 Horizontal travelling distances

If the manipulator goes for short distance (1-4 cells) it cannot reach max. velocity. The servo is accelerating and it must start breaking before reaching the max. velocity.

Then we can describe two cases of motion:

A) **Short travelling distance:**

The Figure 4.2 shows the situation when the servo starts breaking before reaching the max. velocity.

$$v = a.t \ , \ \ s = \frac{1}{2}a.t^2$$

The equation for travelling time is valid for:

1) half distance:

$$t_{\frac{1}{2}} = \sqrt{\frac{2s_1}{a}}$$

2) Total travelling time at full distance:

$$t_t = 2t_{\frac{1}{2}} = 2.\sqrt{\frac{2s_1}{a}} = 2.\sqrt{\frac{s}{a}}$$

s ...... distance to travel (total distance)

s_1 ..... half distance

a ..... acceleration

The acceleration at starting and the decceleration at breaking have the same values.

B) **Long travelling distance:**

If the travelling distance is long enough the servo reaches the maximum velocity and remains at this velocity for some time before breaking, Servodrive then remains in one of the following states. Its velocity and position are given by known equations.

accel./deccel	*constant speed*
$v = a.t$	$v = const = v_{max}$
$s = \frac{1}{2}a.t^2$	$s = v.t$
$a = const.$	$a = 0$

1) Acceleration / decceleration time and distance:

$$t_a = t_d = \frac{v_{max}}{a}$$

$$s_a = s_d = \frac{1}{2}a.t_a^2 = \frac{a}{2}\frac{v_{max}^2}{a^2} = \frac{v_{max}^2}{2a}$$

2) Time for travelling at $v = v_{max}$

s .... distance to travel (total distance)

s_o ... distance to travel at $v = v_{max}$

$$s_o = s - s_a - s_d$$

$$\Rightarrow s_o = s - 2s_a \Rightarrow \underline{s_o = s - \frac{v_{max}^2}{a}}$$

$$s_a = s_d$$

$$t_o = \frac{s_o}{v_{max}} = \frac{s - \frac{v_{max}^2}{a}}{v_{max}} = \frac{s}{v_{max}} - \frac{v_{max}}{a}$$

$$\underline{t_o = \frac{s}{v_{max}} - \frac{v_{max}}{a}}$$

3) Total time:

$$t_t = t_a + t_o + t_d = 2t_a + t_o$$

$$\underline{t_t = \frac{2v_{max}}{a} + \frac{s}{v_{max}} - \frac{v_{max}}{a}} =$$

$$\underline{t_t = \frac{s}{v_{max}} + \frac{v_{max}}{a}}$$

C) Switching point between case A and case B:

The problem: At what distance occurs the case A ?

At what distance occurs the case B ?

⇒ That switching point is s_{lim}.

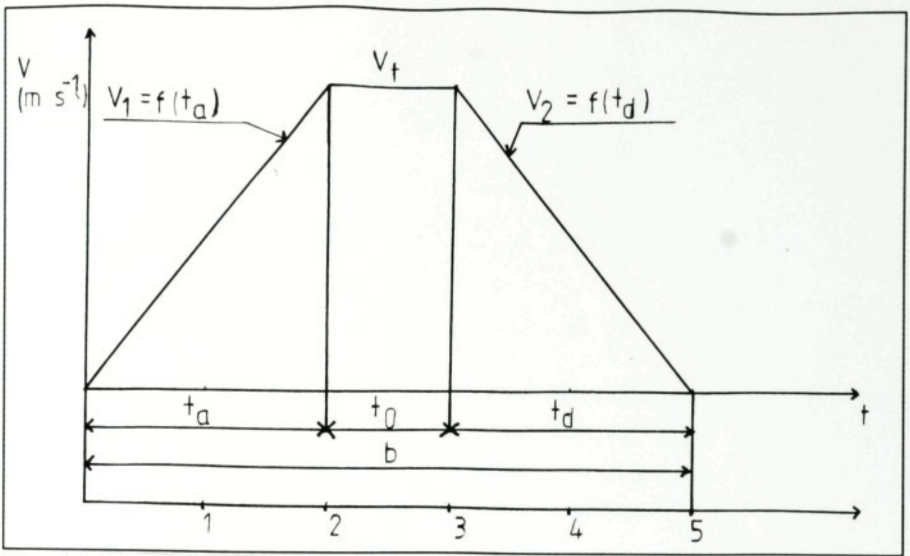


Fig. 4.3 The behavior of the velocity.

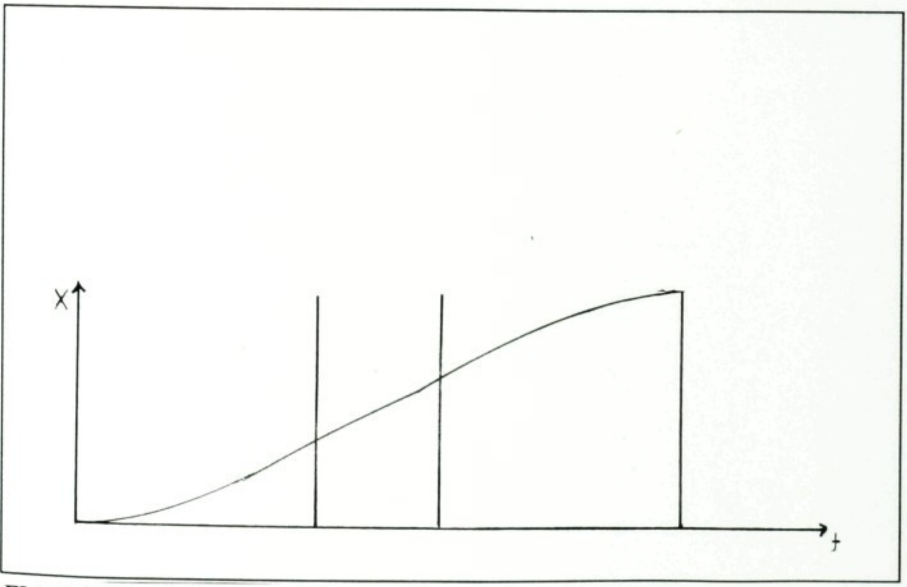


FIg. 4.4 The behavior of the position.

General equations for motion with constant acceleration:

$$v = a.t \rightarrow t_a = t_d = \frac{v_{max}}{a}$$

$$s = \frac{1}{2}a.t^2$$

half distance:

$$s_{\frac{1}{2}} = \frac{1}{2}a(\frac{v_{max}}{a})^2 = \frac{v_{max}^2}{2a}$$

full distance:

$$s_{lim} = 2.s_{\frac{1}{2}} = \frac{v_{max}^2}{a}$$

For our manipulator:

$v_{max} = 2$ [ms^{-1}], a = 1 [ms^{-2}]

Limit distance $s_{lim} = 2^2/1 = 4$ [m]

Modulus of the store is $m_x = 1$ [m], so the S_{lim} equals the travelling over 4 cells.

When the travelling distance is shorter than S_{lim} (5 cells),the case 1 occurs. For the greater or equal distance (5 and more cells) the case 2 occurs.

For example travelling time over 5 cells:

$$t_5 = \frac{v_{max}}{a} + \frac{s}{v_{max}} = \frac{2}{1} + \frac{5}{2} = 2+2,5 =$$

$$\underline{t_5 = 4,5[s]}$$

Table 4.1 Real travelling times of the manipulator 630 (start from the cell No. 1.)

No of cells	Travelling time [s]	No of cells	Travelling time [s]	No of cells	Travelling time [s]
1	-	10	6,5	19	11
2	2	11	7	20	11,5
3	2,82	12	7,5	21	12
4	3,46	13	8	22	12,5
5	4	14	8,5	23	13
6	4,5	15	9	24	13,5
7	5	16	9,5	25	14
8	5,5	17	10	26	14,5
9	6	18	10,5	27	15

Table 4.2

No of cells	Travelling time [s]	No of cells	Travelling [s]	No of cells	Travelling time [s]
28	15,5	39	21	50	26,5
29	16	40	21,5	51	27
30	16,5	41	22	52	27,5
31	17	42	22,5	53	28
32	17,5	43	23	54	28,5
33	18	44	23,5	55	29
34	18,5	45	24	56	29,5
35	19	46	24,5	57	30
36	19,5	47	25	58	30,5
37	20	48	25,5	59	31
38	20,5	49	26	60	31,5

4.2 Calculation of manipulating times of manipulator,s lift

(vertical travelling axes)

There are two cases of the vertical motion, too:

The first case:

When the lift's buggy is lifted up to the next cell only (short distance) then however it reaches the max. velocity at that point it starts breaking (decceleration).

The second case:

When the lifting distance is longer than 1 cell (2 cells and more), the lift's buggy travels for some time at the max. velocity before breaking.

$v_{max} = 0,5$ m/s $\qquad$ a = 0,19 m/s^2

Switching point is:

$$S_{\lim} = \frac{v_{max}^2}{a} = \frac{0,5^2}{0,19} = 1,32\ [m]$$

Manipulating time for:

1m travelling $S < S_{\lim}$, 2m travelling $S > S_{\lim}$

A) Short distance (see olso page 34):

$$t_t = 2.\sqrt{\frac{S}{a}} = 2.\sqrt{\frac{1}{0,19}} = 4,59\ [s]$$

B) Long distance (see olso page 35, 37):

$$t_a = t_d = \frac{v_{max}}{a} = \frac{0,5}{0,19} = 2,63$$

$$t_t = \frac{S}{v_{max}} + \frac{v_{max}}{a} = \frac{S}{0,5} + 2,63$$

Then for $S = 2[m]$

$$t_t = \frac{2}{0,5} + 2,63 = 6,63[s]$$

4.3 Manipulating time calculation

When the manipulator stops at the programmed point, the fork's shifting out on the path $z_f = 0,82$ [m] at the speed $v_f = 0,25$ [m.s^{-1}] follows at time:

$$t_1 = \frac{z_f}{v_f} = \frac{0,82}{0,25} = 3,28\ [s]$$

Than the microstroke of the fork on the path $y_m = 0,06$ [m] at the speed $v_m = 0,025$ [m.s^{-1}] takes the time: (lifting the pallet)

$$t_2 = \frac{y_m}{v_m} = \frac{0,06}{0,025} = 2,4\ [s]$$

The fork is then shifting in at the speed $v_f = 0,25$ [m.s^{-1}] on the path $z_f = 0,82$ [m] at the time:

$$t_3 = \frac{z_f}{v_f} = t_1 = 3,28\ [s]$$

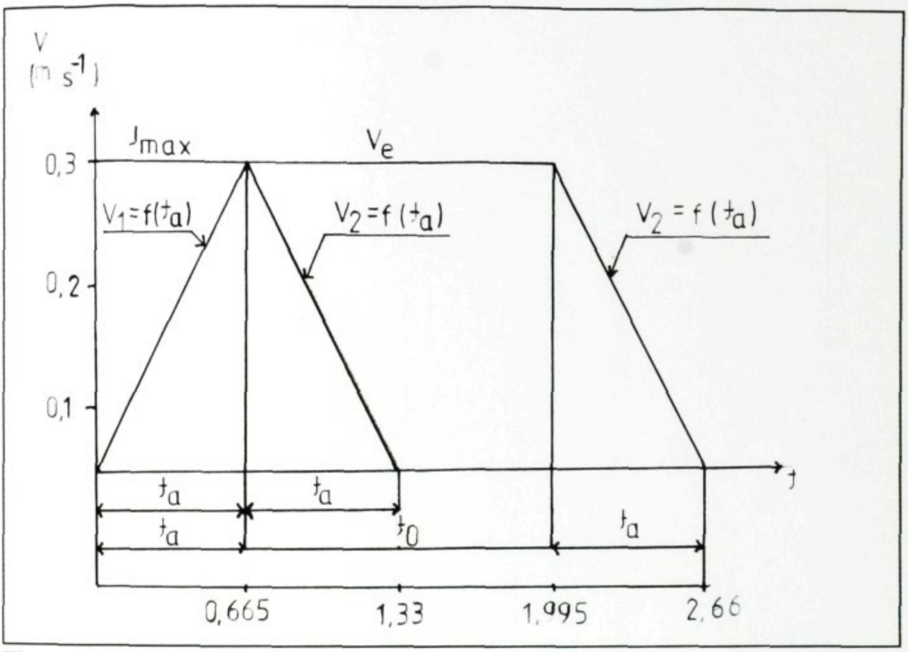


Figure 4.5

After the fork's shifting in the manipulator moves on to the next programmed point.

Note: The pallet's code is read during that movement.

Table 4.3 Manipulating times:

No	Manipulation	Time t [s]
1	The fork's shifting out	3,28
2	Microstroke	2,4
3	The fork's shifting in	3,28
4	Total time	8,96

5. CALCULATION OF SERVOS

Review of the old DC drive calculations:

1) The travel's drive (servo)

The drive is realized by the pinion meshing the rack with the modulus m=5. There,s a gear i=2 attached to the pinion.

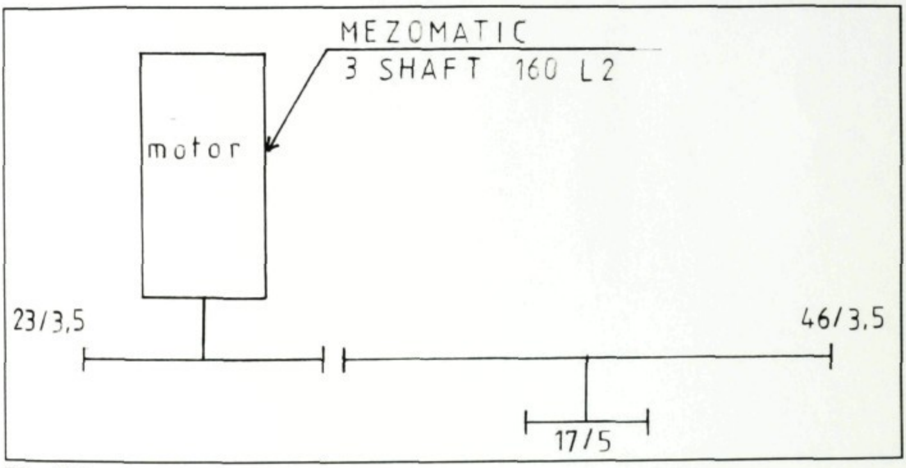


Fig. 5.1

No of the pinion's teeth Z = 17

i = 2 gear's efficiency $\eta_1 = 0{,}9$

traction coefficient of friction $f_t = 0{,}004$

a) The total gear ratio

$$i_T = i.\frac{D}{2} = i.\frac{m.z}{2} = \frac{1}{2}.\frac{5.17}{2} = 21{,}25\ [mm.rad^{-1}]$$

$$i_T = 2{,}125.10^{-2}\ [m.rad^{-1}]$$

b) The manipulator's mass reduction for the engine's shaft

$$J_m = m.i_T^2 = (m_m + m_o).i_T^2$$

$$J_m = (6200 + 630).(2{,}125.10^{-2})^2 = 3{,}084 \ [kg.m^2]$$

$$\underline{J_m = 3{,}084 \ [kg.m^2]}$$

c) Motor's moment of inertia

$$\underline{J_{mot} = 0{,}35 \ [kg.m^2]}$$

d) Total moment of inertia

$$j_{Tot} = J_m + J_{mot} = 3{,}084 + 0{,}35 = \underline{3{,}434 \ [kg.m^2]}$$

e) Angular acceleration on the motor shaft

$$\varepsilon = \frac{a_p}{i_T} = \frac{1}{2{,}125.10^{-2}} = \underline{47{,}06 \ [rad.s^{-2}]}$$

f) Travel's static torque

$$M_o = f_t.m.g.\frac{i_T}{\eta_1.\eta_2} = f_t.(m_m + m_o).g.\frac{i_T}{\eta_1.\eta_2} =$$

$$= 0{,}004.(6200 + 630).9{,}81.\frac{2{,}125.10^{-2}}{0{,}9.0{,}9} =$$

$$\underline{M_o = 7{,}03 \ [N.m]}$$

f_t ... coefficient of rolling resistance

g) Dynamic torque

$$M_d = J_{Tot}.\varepsilon.\frac{1}{\eta_1.\eta_2} = 3{,}434.47{,}06.\frac{1}{0{,}9.0{,}9} =$$

$$\underline{M_d = 199{,}51\ [N.m]}$$

h) Peak torque

$$M_p = M_o + M_d = 7{,}03 + 199{,}51 = 206{,}54\ [Nm]$$

$$\underline{M_p = 206{,}54\ [Nm]} \quad M_p \leq M_{max}$$

i) Critical loading cycle

from the point of view of loading the servomotor has the following characteristics:

- shortest possible cycle time T .
- longest possible acc./decc. time t_a, t_d

According to the manipulating times calculations for travelling over 4 cells Accelaration and decceleration times (see in Fig. 5.2) are

$$t_1 = t_2 = 2\ [s]$$

In accordance to the "manipulating times" (table 4.3) the period of movement of the manipulator fork with the pallet is t_4 = 8,9 [s]. The greatest thermal loading occurs at horizontal motion over 4 cells without vertical motion.

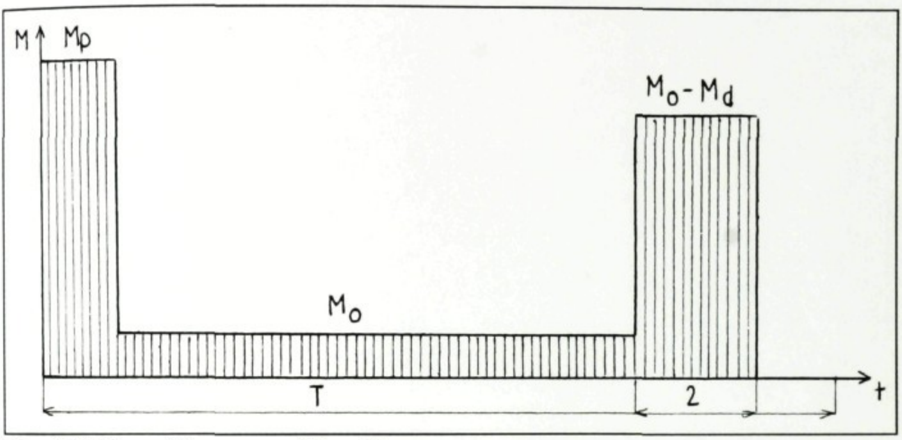


Fig. 5.2 Travelling over 20 cells

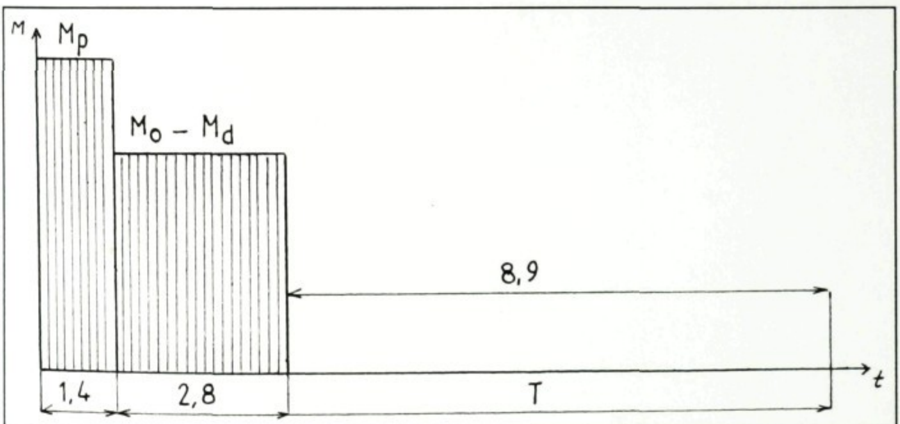


Fig. 5.3 Travelling over 2 cells

$$t_3 = t_4 = 8{,}9 \ [s]$$

$$T = t_1 + t_2 + t_3 = 2 + 2 + 8{,}9 =$$

$$\underline{T = 12{,}9 \ [s]}$$

According to the technical parameters of the MEZOMATIC 3 SHAT 160 L2 servodrive there are valid the following values:

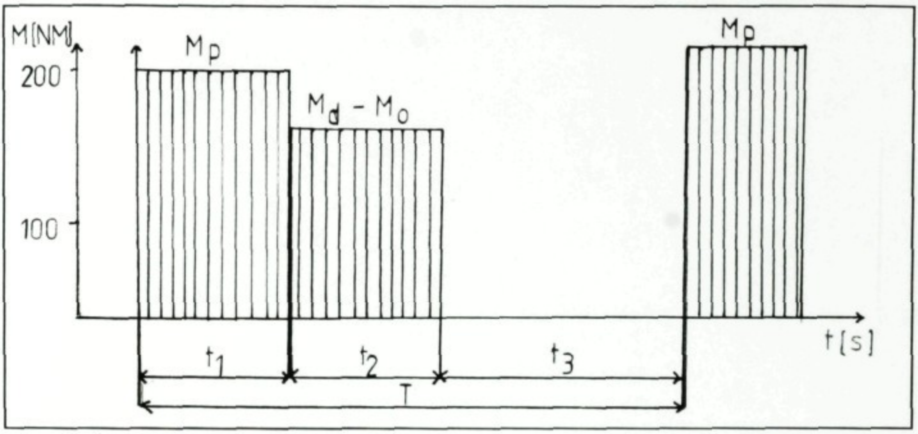


Fig. 5.4 Critical loading cycle

continuous torque

$M_1(at\ 899\ \min^{-1})....0,77[Mn] = 0,77.100 = 77[Nm]$

maximal torque

$M_2(at\ 899\ \min^{-1})....3,5[Mn] = 3,5.100 = 350\ [Nm]$

j) Equivalent torque for warming

The peak torque (M_p) is greater then continuous torque (M_1) so we must calculate thermal loading of the drive.

$$M_{eff} = \sqrt{\frac{(M_p)^2.t_1 + (M_d - M_o)^2.t_2}{T}} =$$

$$= \sqrt{\frac{(206,54)^2.2 + (199,51 - 7,03)^2.2}{12,9}} =$$

$$\underline{M_{eff} = 111\ [Nm]} = 1,45\ M_1$$

In spite of it designed drive can be considered as suitable. It is necessary to take into account that the critical loading cycle will be sporadic. According to the tables "utilization of the shelf manipulator" (tab. 1, 2 and 3) for there suppose to be one manipulation approximately every 2,5 min. Then the cycle time T is not 12,9 sec. but 150 sec. and equivalent torque for this value is only M_{eff} = 32,5 [N.m].

k) Pinion's rotations

$$n_p = \frac{60.\omega}{2\pi} = \frac{60.47,06}{2\pi} =$$

$$\underline{n_p = 449,4 \ [min^{-1}]}$$

angular speed:

$$\omega = \frac{v_p}{p} = \frac{v_p}{\frac{m.z}{2}} = \frac{2}{\frac{5.17}{2}.10^{-3}}$$

$$\underline{\omega = 47,06 \ [s^{-1}]}$$

l) The MEZOMATIC drive's velocity

$$n_d = \frac{1}{i}.n_p = 2.449,4 =$$

$$\underline{n_d = 898,8 \ [min^{-1}]}$$

2) The lift's drive (servo)

The drive is realized by the chain wheel meshing the double-strand chain.

There's a worm transmission MKG 160-01-04-25x1500 (VSS Košice) added to the chain wheel.

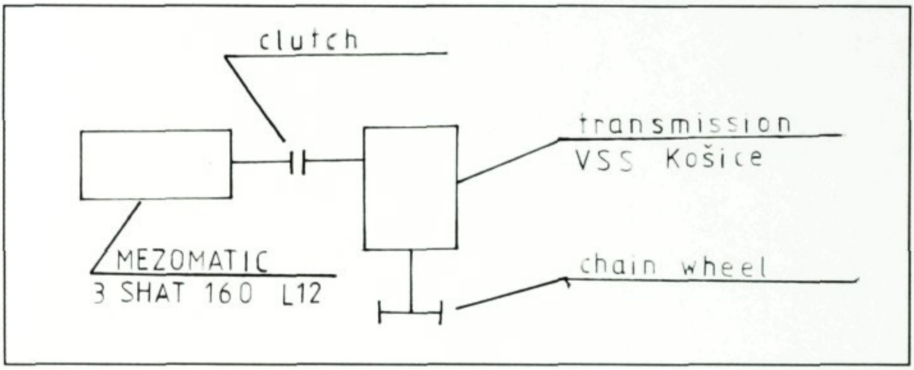


Fig. 5.5

- the real gear ratio of the worm gear transmission according to the catalogue i = 25,5
- double-strand chain 20A CSN 023311, gauge distance t = 75 [mm] diameter of the chain wheel's gauge distance circle

$$D_t = t.x = 31,75.5,4422 = 172,79\ [mm]$$

- the transmission's efficiency $\eta = 0,82$

a) The total gear ratio

$$i_T = i.\frac{D_t}{2} = \frac{1}{25,5}.\frac{0,173}{2} =$$

$$i_T = 3,39.10^{-3}\ [m.rad^{-1}]$$

b) <u>The manipulator's mass reduction for the motor shaft</u>

$$J_{red} = (m_o + m_v + m_p).i_T^2$$

$$J_{red} = (630+1018+755).(3{,}39.10^{-3})^2 =$$

$$\underline{J_{red} = 2{,}76.10^{-2}\ [kg.m^2]}$$

c) <u>Motor's moment of inertia</u>

$$\underline{J_m = 0{,}35\ [kgm^2]}$$

d) <u>Total moment of inertia</u>

$$J_{Tot} = J_{red} + J_m = 2{,}76.10^{-2} + 0{,}35 =$$

$$\underline{J_{Tot} = 0{,}3776\ [kg.m^2]}$$

e) <u>Angular acceleration</u>

$$\varepsilon = \frac{a_z}{i_T} = \frac{0{,}19}{3{,}39.10^{-3}} = \underline{56{,}05\ [rad.s^{-2}]}$$

f) <u>Moment for the stroke</u>

$$M_o = [(m_v + m_o) - m_p].g.\frac{i_T}{\eta} =$$

$$= [(1018+630) - 755].9{,}81.\frac{3{,}39.10^{-3}}{0{,}82} =$$

$$\underline{M_o = 36{,}2\ [N.m]}$$

g) Dynamic moment

$$M_D = J_{Tot}.\frac{\varepsilon}{\eta} = 0,3776.\frac{56,05}{0,82} =$$

$$\underline{M_D = 25,81\ [N.m]}$$

h) Peak moment

$$M_p = M_o + M_D = 36,2+25,81 = 62,01\ [Nm]$$

$$\underline{M_p = 62,01[Nm]}$$

i) Critical loading cycle

$$t_1 = t_2 = 2,29\ [s],\ t_3 = 8,96\ [s]\ \textit{according table}4.3$$

$$T = 13,54\ [s] = t_1+t_2+t_3$$

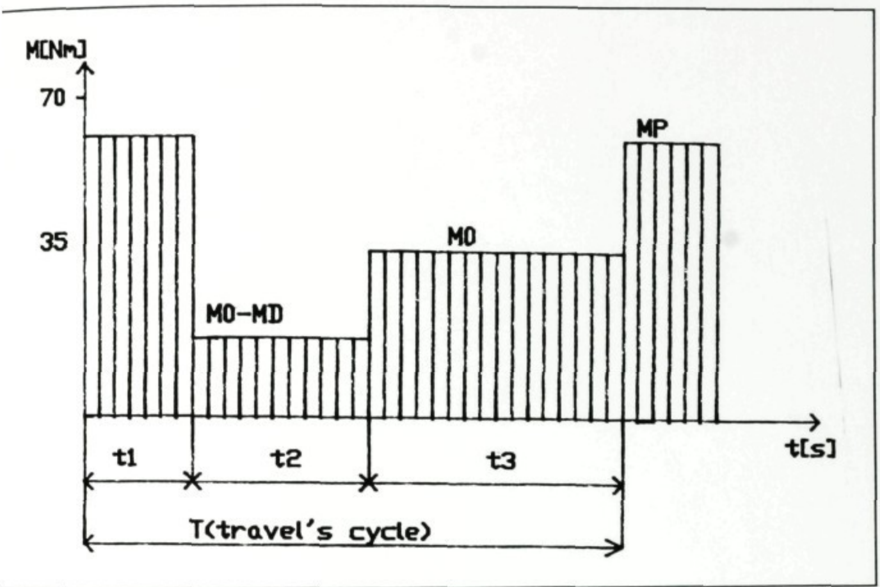
According to the technical parameters of MEZOMATIC 3 SHAT 160L2 Servodrive there are valid the following values.

continuous torque

$$M_1(at\ 1409\ \min^{-1})....0,45[Mn] = 0,45.100 = 45\ [Nm]$$

Maximal torque

$$M_2(at\ 1409\ \min^{-1})....2[Mn] = 2.100 = 200\ [Nm]$$



'ig. 5.6

:alculation of equivalent toque for warming

$$M_{eq} = \frac{\sqrt{(M_p)^2.t_1 + (M_o - M_D)^2.t_2 + (M_o)^2.t_3}}{T}$$

$$M_{eq} = \frac{\sqrt{3845{,}24.2{,}29 + (107{,}95).2{,}29 + 1310{,}44.8{,}96}}{13{,}54} = 39{,}188 \ [Nm]$$

Equivelent torque is lower than continuas torque (45 Nm) ·

NEW DESIGN

- Horizontal drive

1) Estimated nominal torque of motor

- old motor: 100 Nm/300 rpm

77 Nm/900 rpm (limit of the torque at given velocity)

- new motor: 18 Nm/6000 rpm - nominal

18 Nm/5000 rpm - working point

$$60\ Nm.\frac{900}{5000} = 10,8\ [Nm]$$

We tried to use motor Simens 1FT 5074

14 Nm/6000 rpm

working velocity = 5000 rpm

J_m = 0,0037

a) Total gear ratio:

$$i_{Tot} = \frac{v\ [m/s]}{\omega\ [rad/s]} = \frac{2}{5000.\frac{2\pi}{60}} = 3,82.10^{-3}\ [m/rad]$$

$$J_m = 6800.(3,82.10^{-3})^2 = 0,099\ [kgm^2]$$

$$\frac{J_m}{j_{mot}} = \frac{0.099}{0,0037} = 26,8$$

Ratio J_m/J_{mot} = 26,8 is rather high for good regulation. We try greater motor 1FT 5132.

60 Nm/3000 Maximal speed

60 Nm/2600 Working point

$J_{mot} = 0{,}0464$

* Total gear ratio:

$$i_{tot}\ \frac{v}{w} = \frac{2}{2600.\frac{2\pi}{60}} = 7{,}35.10^{-3}$$

$$J_m = 6800.(7{,}35.10^{-3})^2 = 0{,}367$$

$$\frac{J_m}{J_{mot}} = \frac{0{,}367}{0{,}0464} = 7{,}9$$

The old motor was a little under-sized. The new one has nominal torque on the pinion 3 times greater. It allows greater acceleration and decceleration.

Drive Siemens SIMODRIVE Series 611 (AC drive, motor with rare earth permanent magnets).

Motor 1FT5 132:

$M_{max} = 120$ Nm $n_{max} = 3000$ rpm

$M_{nom} = 60$ Nm m $= 75$ kg

$J_m = 0{,}0464$ kgm^2 length $= 590$

cross section 260

old motor velocity: 898,8 rpm

new motor velocity: 2600 rpm (working point selected).

We used the old gear and additional pair of gears

$$\underline{i = 2600/898{,}8 = 2{,}893}$$

The pinion will have 20 teeth so the wheel will have 57 teeth. The ratio of the additional gear box is then

$$\underline{57/20 = 2{,}85}$$

Given: efficiency of 2 pairs of gears

$\eta_1 = 0{,}9 \,.\, 0{,}9 = 0{,}81$

$\eta_2 = 0{,}9$

m = motor 1FT5 132

J_m = inertia of the motor

$J_m = 0{,}0464$ kgm^2

v_{max} = max velocity

v_{max} = 3000 rpm

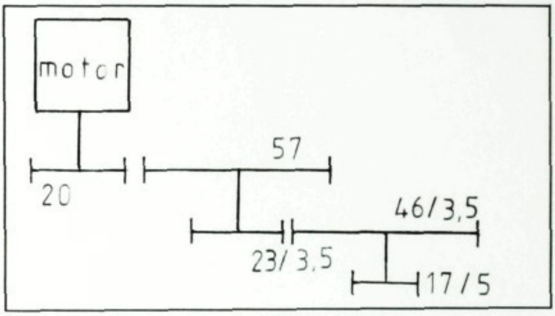


Fig. 5.7 Proportion of the gears

a) Total gear ratio

$$i_T = i_1 . i_2 . \frac{D}{2} = \frac{20}{57} . \frac{23}{46} . \frac{17.5.10^{-3}}{2} =$$

$$\underline{i_T = 7{,}456.10^{-3}\ [m/rad]}$$

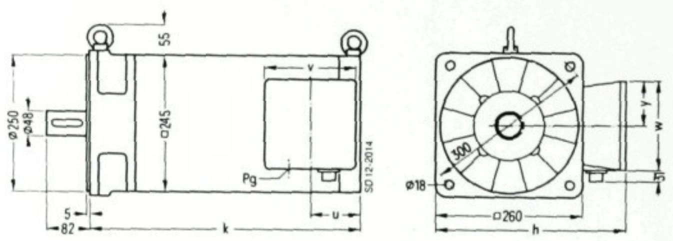
b) The manipulator's mass reduction for the motor's shaft

$$J_m = m.i_T^2 = (m_m + m_o).i_T^2$$

$$J_m = (6200+630).(7{,}456.10^{-3})^2 =$$

$$\underline{J_m = 0{,}37969\ [kg.m^2]}$$

Standardausführung mit Klemmenkasten



Motor	Maß k
1FT5 132	429
1FT5 134	479
1FT5 136	529
1FT5 138	604

Maß	Klemmenkasten Typ gk 230	330	420
h	316,5	330,5	332
u	86	86	86
v	117	132	162
w	122	152	162
y	58,5	72	81
Pg	29	36	36/42

Motoren 1FT5 132 bis 1FT5 138: Anschluß über Klemmenkasten Typ gk 230, 330 bzw. 420

Fig. 5.8 Horizontal 1FT5132

c) Motor's moment of inertia

$$\underline{J_{mot} = 0{,}0464\ [kgm^2]}$$

d) Total moment of inertia

$$J_{Tot} = J_m + J_{mot} = 0{,}37969 + 0{,}0464 =$$

$$\underline{J_{Tot} = 0{,}426\ [kg.m^2]}$$

e) Angular acceleration on the motor shaft

$$\varepsilon = \frac{a_p}{i_T} = \frac{1}{7{,}456.10^{-3}} = \underline{134{,}120\ [rad.s^{-2}]}$$

f) Travel's torque

$$M_o = f_t.m.g.\frac{i_T}{\eta_1.\eta_2} =$$

$$= f_t.(m_m + m_o).g.\frac{i_T}{\eta_1.\eta_2} = 0{,}004.(6830).9{,}81.\frac{7{,}456.10^{-3}}{0{,}9.0{,}9} = \underline{M_o = 2{,}467\ [N.m]}$$

g) Dynamic torque

$$M_d = J_{Tot}.\varepsilon.\frac{1}{\eta_1.\eta_2} = 0{,}426.134{,}120.\frac{1}{0{,}9.0{,}9} =$$

$$\underline{M_d = 70{,}5\ [N.m]}$$

h) Peak torque

$$M_p = M_o + M_d = 2{,}467 + 70{,}5 = 73{,}0\ [Nm]$$

$$\underline{M_p = 73{,}0[Nm]} \quad M_p \le M_{max}$$

Peak torque is lower than maximum torque

As the peak torque is greater than the nominal torque, it is necessary to check the motor's up warming during the working cycle according to the Fig. 5.9.

i) Equivalent torque for warming

$$M_{eff} = \sqrt{\frac{(M_p)^2.t_1 + (M_d - M_o)^2.t_2}{T}} =$$

$$= \sqrt{\frac{(73)^2.2 + (70{,}5 - 2{,}5)^2.2}{12{,}9}} = \underline{M_{eff} = 39{,}3\ [Nm]}$$

j) The critical loading cycle

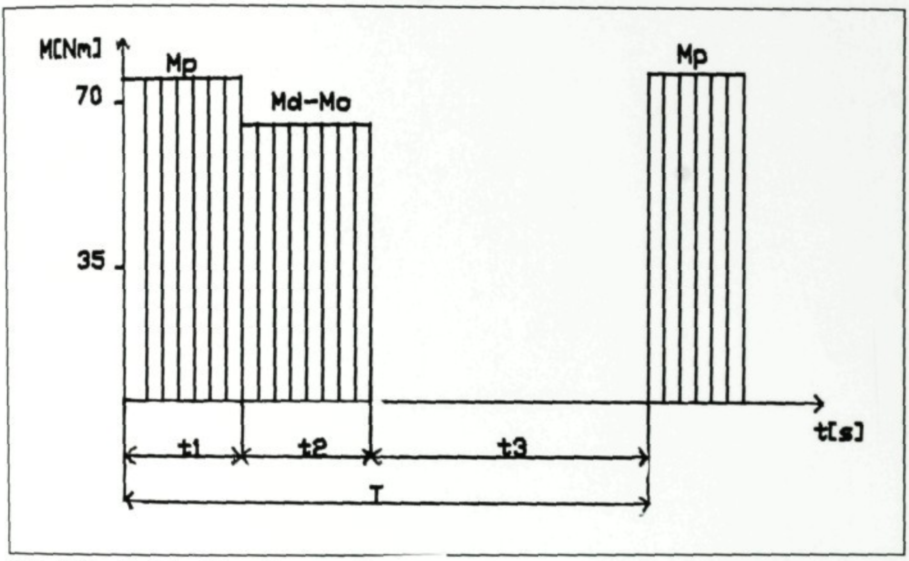


Fig. 5.9 Critical loading cycle

The equivalent torque is smaller than the nominal torque so the drive will not be overheated during work.

Note: The drive is oversized from the stand point of the loading torque. This provides the great inertia of the load to obtain good regulation while the pinion rotation stays the same as in the old design.

k) The drive's velocity

$$n_d = \frac{1}{i_1 . i_2} . n_p = \frac{1}{0,350.0,5} . 449,4 =$$

$$n_d = 2568\ [\min^{-1}] = 86\%\ of\ n_{max}$$

NEW DESIGN

vertical drive

2. The lift's drive

old design: motor velocity 1409 min^{-1}

nom. torque 45 Nm at 1409 min^{-1}

reflected inertia of the load 0,0276 kgm^2

new design: max motor velocity 6000 min^{-1}

working velocity 5000 min^{-1}

neccessary nom. torque 45.1409/5000 = 12,6 Nm

motor 1FT 5074 M_{nom} = 14 Nm

J_m = 0,00367 kgm^2

reflected inertia $0,0276(1409/5000)^2 = 0,00219$

Reflected inertia nearly equal to the inertia of the motor gives the best regulation capacity.

Possible new design of the gearing:

old gearing: worm gear 1:25,5

new gearing: 1/25,5.1409/5000=1/90,5=0,011

⇒ a gearbox with the ratio 1:90,5 is not available.

In that case we have to use old worm gear transmission with the additional gearbox. But for this motor is not available standard additional gear box. Then we tray to calculate a new Design, becouse we want to use a pair of aditional gears, so we use only 3000 rpm as working velocity of the motor.

working velocity 3000 min^{-1}

additional gear ratio i_1 = 1409/3000 = 1/2.13

nom. torque ≥ 45.(1409/3000) = 21,1 Nm

1FT5076 M_{max} = 36 Nm

M_{nom} = 18 Nm   4000 rpm max

J_{mot} = 0,00509 kgm^2

reflected inertia 0,0276$(1409/3000)^2$=0,00609 kgm^2

Gear ratio i_1 = 20/43 = 1/2,15

The transmission's effect for new design η = 0,82 . 0,9=0,738

a) Total gear ratio

$$i_T = i.\frac{D_t}{2} = 25{,}5.\frac{1}{2{,}15}.\frac{0{,}173}{2} =$$

$$i_T = 0{,}00158 \ [m/rad]$$

b) The manipulator's mass reduction for the motor shaft

$$J_{red} = (m_o + m_v + m_p).i_T^2$$

$$J_{red} = (630 + 1018 + 755).(0{,}00158)^2 =$$

$$J_{red} = 5{,}99.10^{-3}$$

c) Motor's moment of inertia

$$J_m = 0{,}00509 \ [kgm^2]$$

d) Total moment of inertia

$$J_{Tot} = J_{red} + J_m = 5{,}99.10^{-3} + 5{,}09.10^{-3} =$$

$$\underline{J_{Tot} = 0{,}01108\ [kg.m^2]}$$

e) Angular acceleration

$$\varepsilon = \frac{a_z}{i_T} = \frac{0{,}19}{0{,}00158} = \underline{120{,}253\ [rad.s^{-2}]}$$

f) Moment for the stroke

$$M_o = [(m_v + m_o) - m_p].g.\frac{i_T}{\eta} =$$

$$= [(1018 + 630) - 755].9{,}81.\frac{1{,}58.10^{-3}}{0{,}738} =$$

$$\underline{M_o = 18{,}755\ [N.m]}$$

g) Dynamic moment

$$M_o = J_{Tot}.\frac{\varepsilon}{\eta} = 0{,}01108.\frac{120{,}253}{0{,}738} =$$

$$\underline{M_o = 1{,}8054\ [N.m]}$$

h) Peak moment

$$M_p = M_o + M_d = 18{,}8 + 1{,}8 = 20{,}6 \ [Nm]$$

$$\underline{M_p = 20{,}6 [Nm]}$$

$$M_p < M_{\max} \ but \ M_p > M_{nom} \ (18 \ Nm)$$

Because the motor used in the drive has permissible torque 22 Nm at 100 degree of Kelvin temperature raise it's not necessary to calculate equivalent torque for warming.

l) The drive's velocity

$$n_d = \frac{1}{i}.1409 \ rpm = \frac{1}{\frac{20}{43}}.1409 =$$

$$\underline{n_d = 3029 \ rpm} \rightarrow$$

76% of motor's maximum velocity

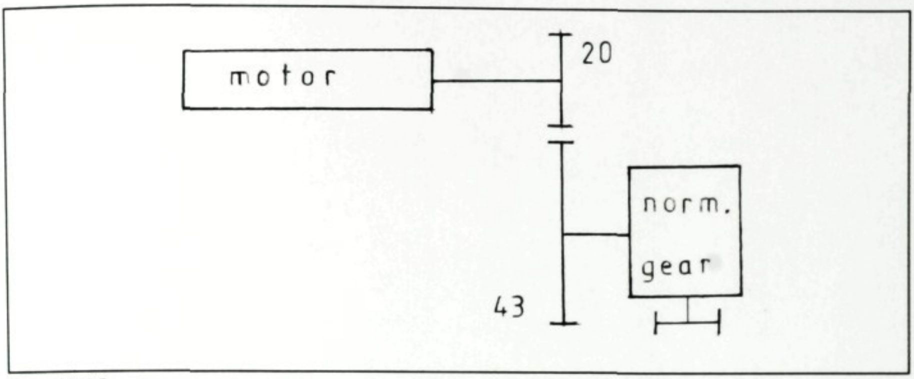
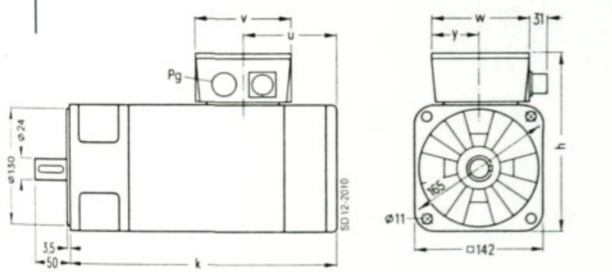


Fig. 5.10



Motoren 1FT5 072 bis 1FT5 076. Anschluß über Klemmenkasten Typ gk 130, 230, 330 bzw. 420

Motor	Maß k
1FT5 072	273
1FT5 074	323
1FT5 076	373

Maß	Klemmenkasten Typ gk			
	130	230	330	420
h	201	206	220	218
u	103,5	105,5	115	115
v	105	117	132	162
w	110	122	152	162
y	52,5	58,5	72	81
Pg	29	29	36	42

Fig. 5.11 dimentioned sketch of the motors 1FT507x

6. CONCLUSION

Using the new drives with AC motors for manipulator shows this motor to be smaller than the old one.

The second advantage of the new design is better J_m/J_{mot} ratio which brings better regulation capacity.

Tab. 6.1 Comparation of the new and old drives

	HORIZONTAL DRIVE	VERTICAL DRIVE
OLD	type 3 SHAT 160 L2 (MEZ Brno) M_{nom} = 100 Nm m = 174 kg I_{nom} = 70 A	type 3 SHAT 160 L2 (MEZ Brno) M_{nom} = 100 Nm m = 174 kg I_{nom} = 70 A
NEW	type 1FT 3132 (Siemens) M_{nom} = 60 Nm m = 75 kg I_{nom} = 60 A	type 1FT 5076 (Siemens) M_{nom} = 18 Nm m = 21 kg I_{nom} = 30 A

- The difference between old and new horizontal drive, which is about 100 kg, causes the difference between their working areas.
- The same result is caused by the difference between vertical drives, which is 150 kg.
- The difference in nominal currents leads to smaller and cheaper amplifier.

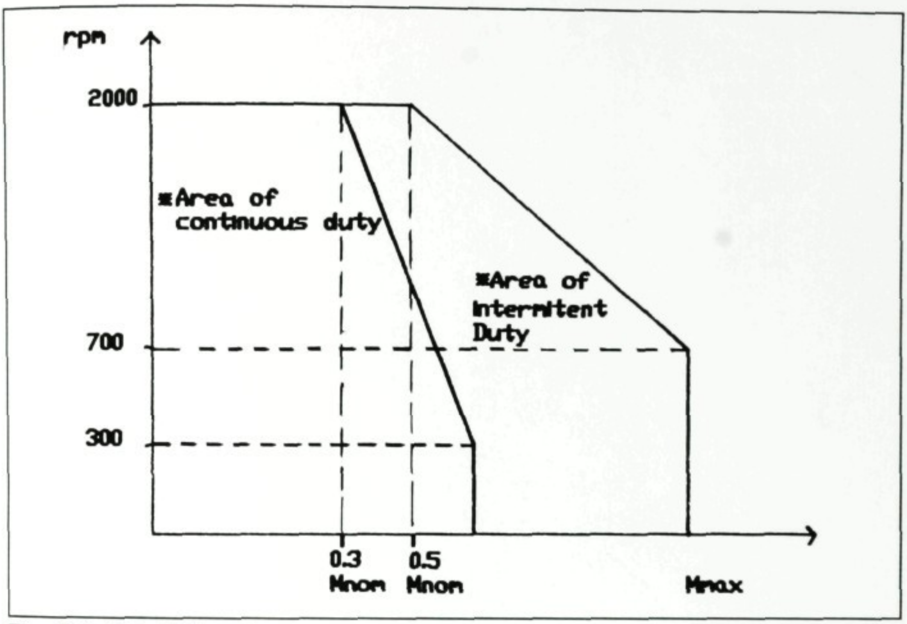


Fig. 6.1 Old DC motor

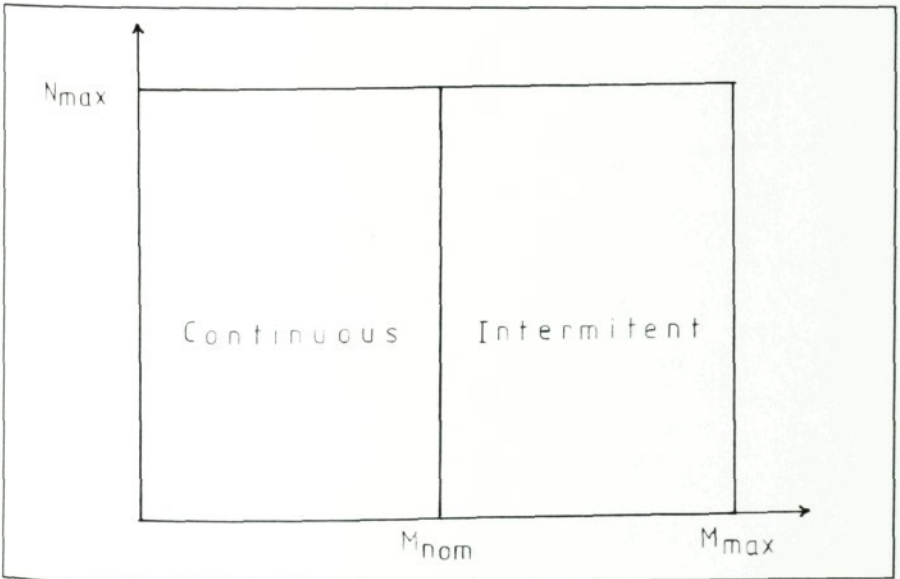


Fig. 6.2 New AC motor

ACKNOWLEDGEMENT

At the end of my diploma project I wish to thank my Supervisor Ing. Jan Skalla, CSc. from Department of manufacturing systems for his valuable contribution in solving this project. And I want to thank the head of Manufacturing Systems Department Doc. Ing. Premysl Pokorný CSc. for his help and every teacher in this University who advised me and helped me accomplish my study in the faculty of Mechanical Engineering in the Technical University in Liberec.

REFERENCE

/1/ HARTLEY, John: FMS at work. IFS (Publications), UK, 1984.

/2/ Technická zpráva a návod na obsluhu (Technical report and operating instruction). TOS Olomouc, VÚOSO Treneín, 1983.

/3/ All Digital AC Servodrives for Speed Control. Yaskawa, Japan 1993.

/4/ Siemens Umrichter system SIMODRIVE 611 (katalog SD 23), (Amplifiers SIMODRIVE 611), 1991.

/5/ Siemens Drehstrom Servomotoren 1FT5 (katalog SD 12), (AC Servomotors Siemens 1FT5), 1991.

/6/ Houša a kol. : Konstrukce eíslicové řízených obrabecích strojů. (Design of the NC Machine Tools). SNTL Praha 1985.