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APPLICATION OF CONTROL THEORY IN INDUSTRIAL DYNAMIC SYSTEM

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ABSTRACT

This paper describes the implementation and part development of a digital simulation programme for an industrial dynamic system (a customer-producer employment case-study as formulated by J.W.Forrester). It has been shown that with the aid of control theory, the major system details were described in a block diagram. The block diagram describing each sector of the model is constructed and then the complete block diagram is established. It is then used to determine the initial conditions of the system. A digital simulation program was developed in "BASIC" language A subroutine was developed to calculate the third order delays occuring in the system. A step function of the independent variable" demand" entering the customer sector was changed from 1000 u/w to 1100 u/w. The system shows a periodic fluctuations in response to the input step with a damping frequency 0.062 rad/w. The system sensitivity was also examined by changing the time for labour adjusting from 10 weeks to 5 weeks which leads to a more stable system.

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1. DESCRIPTION OF THE MODEL

The dynamic model discussed in this paper |1| resulted from a case study of an actual company in the electronic components industry. The product is a high quality electronic component such as precision potentiometer, manufactured by the company and is used by the customer in military and industrial equipment. The two major sectors of the system are shown in fig.1

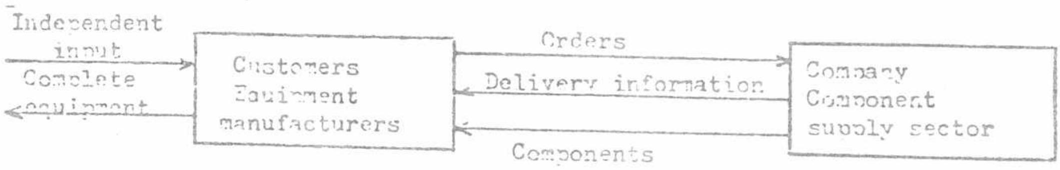


Fig. 1 Major Sectors

orders flow from the customer to the company. Components flow from company to the customer as does delivery information indicating the time required from ordering until delivery.

1.1. Major System Details Fig.2 :

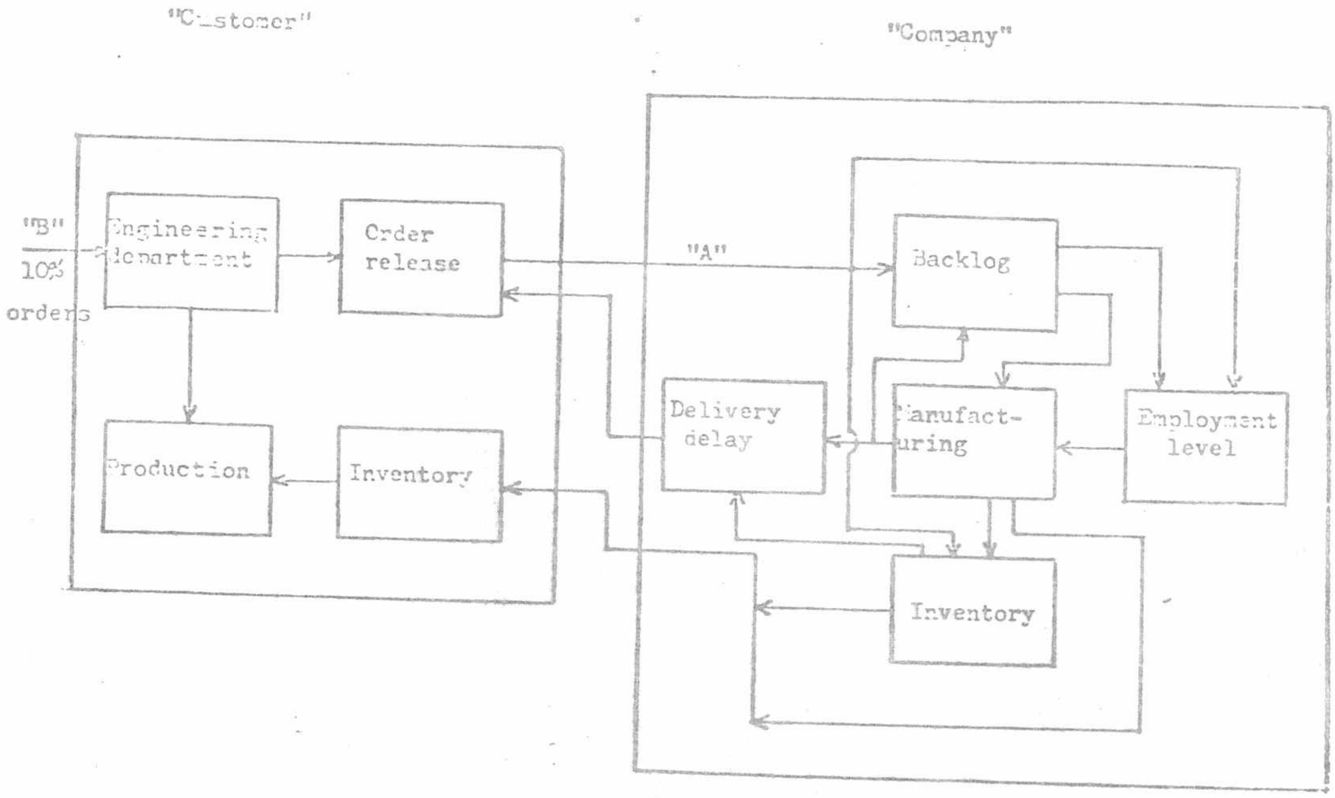


Fig.2 System Details.

A.. incoming orders to the company, it depends on how well the company satisfies the demands of its customer .

B.. orders rate from the purchasers of final equipment to the equipment

6 manufacturers & is independent of company behaviour.

At the customer, dynamic behaviour depends on how the customers respond to changes in delivery delays by the company.
At the company, some orders are filled from inventory and some are made specifically to customer order. The state of inventory determines the fraction of orders that could be filled from stock. Manufacturing to customer's special order needs to be included as well as manufacturing to rebuild inventory. The production rate is determined by the level of employment.

Several factors can be omitted such as manufacturing space, capital equipment and material. Profit and cashlow are not integral parts of the system but a simple profit calculation and cashflow are included to provide a rough indicator of the system performance.

1.2. Mathematical Model of the System

The system consists of |9| sections
- Order Filling, Inventory Reordering, Manufacturing, Material Ordering, Labour, Delivery-Delay Quotation Customer Ordering, Cash Flow, Profit & Divedends

2. BLOCK DIAGRAM OF THE SYSTEM

2.1. General

The equations govering the system are rearranged according to the sequence of activities .|2|

The block diagram of each sector was constructed by the aid of Laplace Transforms and then the complete block diagram was constructed. Then it was used to determine the initial conditions applying simple control theory.

2.2. Block Diagrams of Different Sectors

2.2.1. Order filling sector

This sector of the model includes the inventory of finished goods and criteria that determine whether or not an incoming order can be filled from inventory. The block diagram is shown in figure 3 .

From the block diagram figure 3 . the level in clerical process at the factory "RCF" is the integral of the difference between requisition rate received at the factory "RRF" and the sum of requisition rate filled from inventory "RFIF" and the requisition rate manufactured to order, "RMOF".

The shipping orders at factory "SOF" is the integral of the difference between "RFIF" and the shipments from inventory "SIF". The actual inventory "IAF" is the integral of the difference between manufacturing rate for inventory "MIF" and "SIF".

By the same way the block diagram describing the other sectors may be obtained |2| .

2.3. Determination of Initial Conditions

2.3.1. Initial conditions from system equations

The rearranged system equations |2| were used in computer program and also to enable initial conditions to be inserted appendix B,2

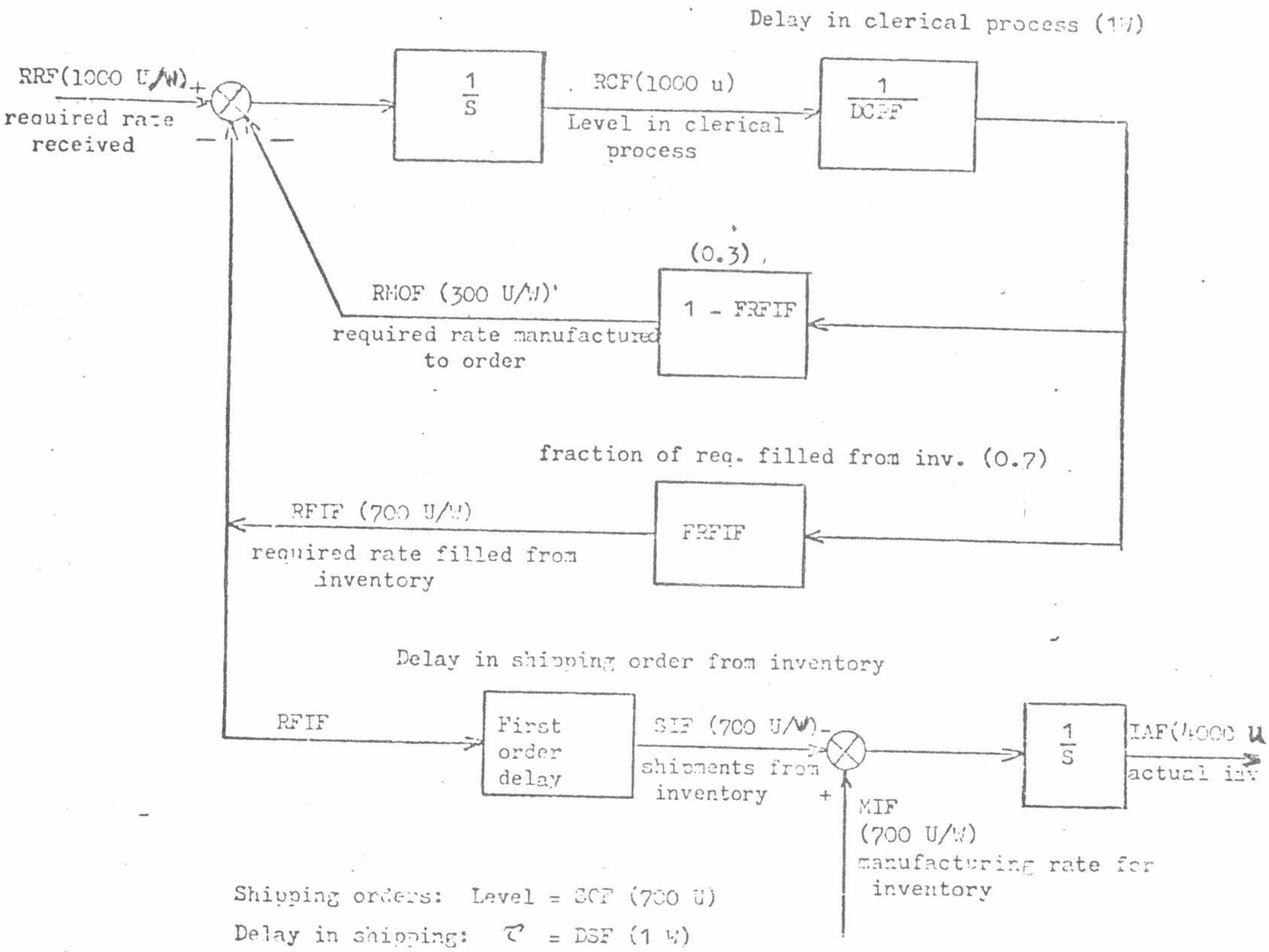


Fig.3. Order Filling Sector.

2.3.2. Initial conditions from block diagram

Initial conditions can be obtained |4| simply from the block diagram by applying 2 simple rules.

- . At any summing junction the sum of inputs is equal to the outputs.
- . If the system is in equilibrium, the inputs to all integrators must be zero.

The complete block diagram including inital conditions is shown in figure.4

3. DEVELOPMENT OF COMPUTER PROGRAM

3.1. Brief Description of the Program

A computer program was made in "BASIC" language using the rearranged equations of the system |2|

The simulation time interval DT was taken to be 0.25 weeks which is much smaller than the smallest time constant in the system (smallest time constant was 1 week) to ensure that the obtained results represented the true system sufficiently well.|3|

An input step of 10% was introduced at the 8th week to change the independent variable demand entering the customer sector from 1000 (u/w) to 1100 (u/w). The printing interval was every 4 weeks.

A subroutine was developed to calculate the third order delays occuring in the system. The program "PROGX" was run and results were obtained for the following outputs.

- . "BLTPC" Backlog total in percentage of initial value (per cent).
- . "IAFPC" Inventory actual at factory in percentage of initial value
- . "IDFPC" Inventory desired at factory in percentage of initial value
- . "MENPC" Men producing at factory in percentage of initial value
- . "RRFPC" Requisitions received at factory in percentage of initial value
- . "FRFPC" Fraction of requisitions filled from inventory in percentage
- . "CASPC" Cash balance in percent of initial value
- . "DQDF" Delay in quoted delivery at factory in weeks.

program "PROCX" in program listing|3.4.1|,|2 |

3.2 Dynamic Behaviour of the System

From figures 5. the system shows a periodic fluctuation in response to the input step. (also figure 6,7).

The period of fluctuation is about 100 weeks (damping frequency wd= 0.062 rad/w). The attenuation was about 50% per cycle and each employment "MENPC" peak measured from the steady state value falls to about one half of the amplitude of the preceding peak. Employment peaks "MENPC" and incoming order rate "RRFPC" peaks occur about the same time (figure 5.) From (figure 5). the cashflow "CASPC" is seen to rise by 5% before falling, whilst inventory "IAFPC" (in figure 6). is being depleted. Cashflow decreases during the time of inventory accumulation before it rises again to a higher level. Fluctuation in factory delivery delay "DQDF" (figure 7). feeding back to the customer, causes fluctuation in the incoming-order rate "RRFPC" (figure 5). System sensitivity was examined by changing the time for labour adjusting "TLCF" from 10 weeks to 5 weeks (the is a reduction in time constant for labour change).

From figure 8 for "MENPC", the employment is adjusted more quickly than before which leads to a more stable system as shown in figure 9 for "BLTPC".

4. CONCLUSIONS

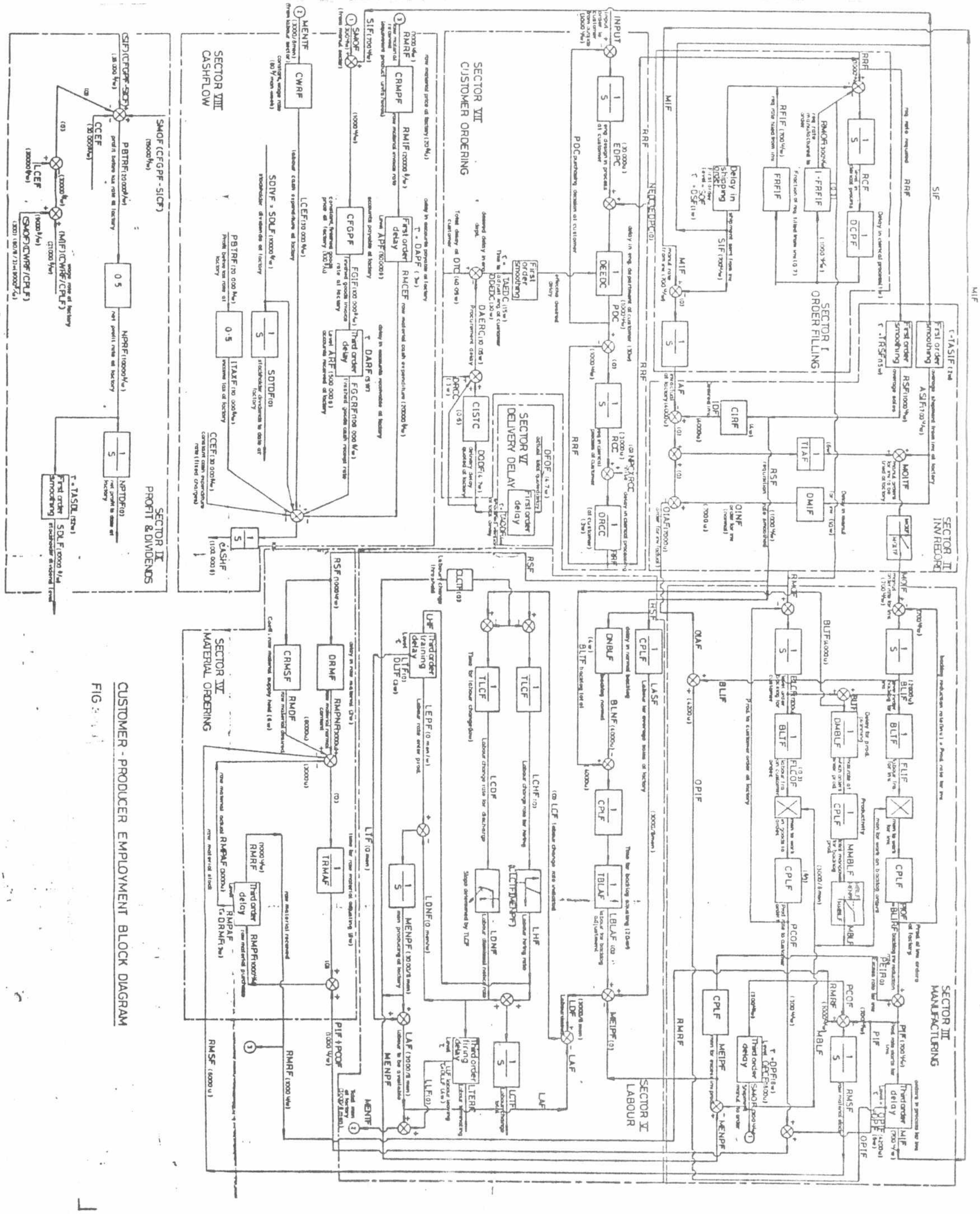
1. It has been shown that control theory may be used to analyse a management system. From a block diagram the interactions between the different activities become evident. The feedback variables are also clear. The block diagram can be treated as a control engineering problem and initial conditons for the equilibrium states can be evaluted.
2. It was possible to computerise the customer-producer employment case study as given by J.W. Forrester using "BASIC" language.
3. Sensitivity analysis was implemented for one parameter. The effect of change of this parameter on the stability of the system was investigated and found not to be serious.

It is recommended that further study should be made to apply analytical techniques taking account of some of the non-linear elements.

REFERENCES

1. Jay. W. Forrester Industrial Dynamics The M.I.T Press Dec. 1965.
2. S.E.ZAKI customer-producer case study M.S.C, Hatfield Polytechnic, Dec. 1978.
3. Jay. W. Forrester Principles of Dynamics Wright Allen Press.

4. Brain Porter & Roger Crossley Modal Control Theory and Applications Taylor & Francis Ltd 1972.



CUSTOMER - PRODUCER EMPLOYMENT BLOCK DIAGRAM

FIG.

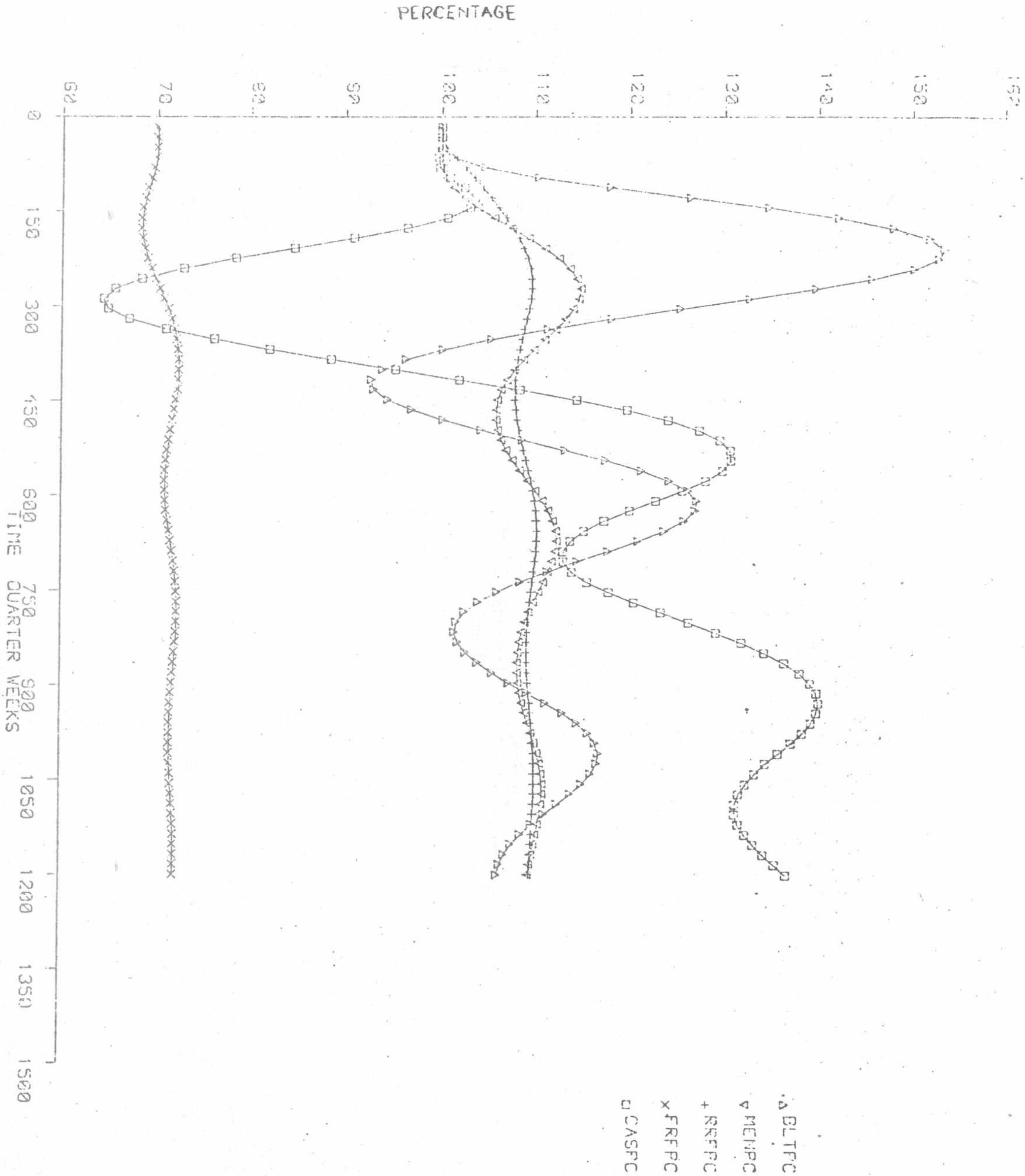


Fig.5.

BLTPC: Backlog total in percentage of initial value

MENPC : Men producing at factory in percentage of initial value.

PRFPC : Requisitions received at factory in percentage of initial of value

FRFPC : Fraction of requisitions filled from inventory in percentage of initial value.

CASPC : Cash belance in percent of initial value.

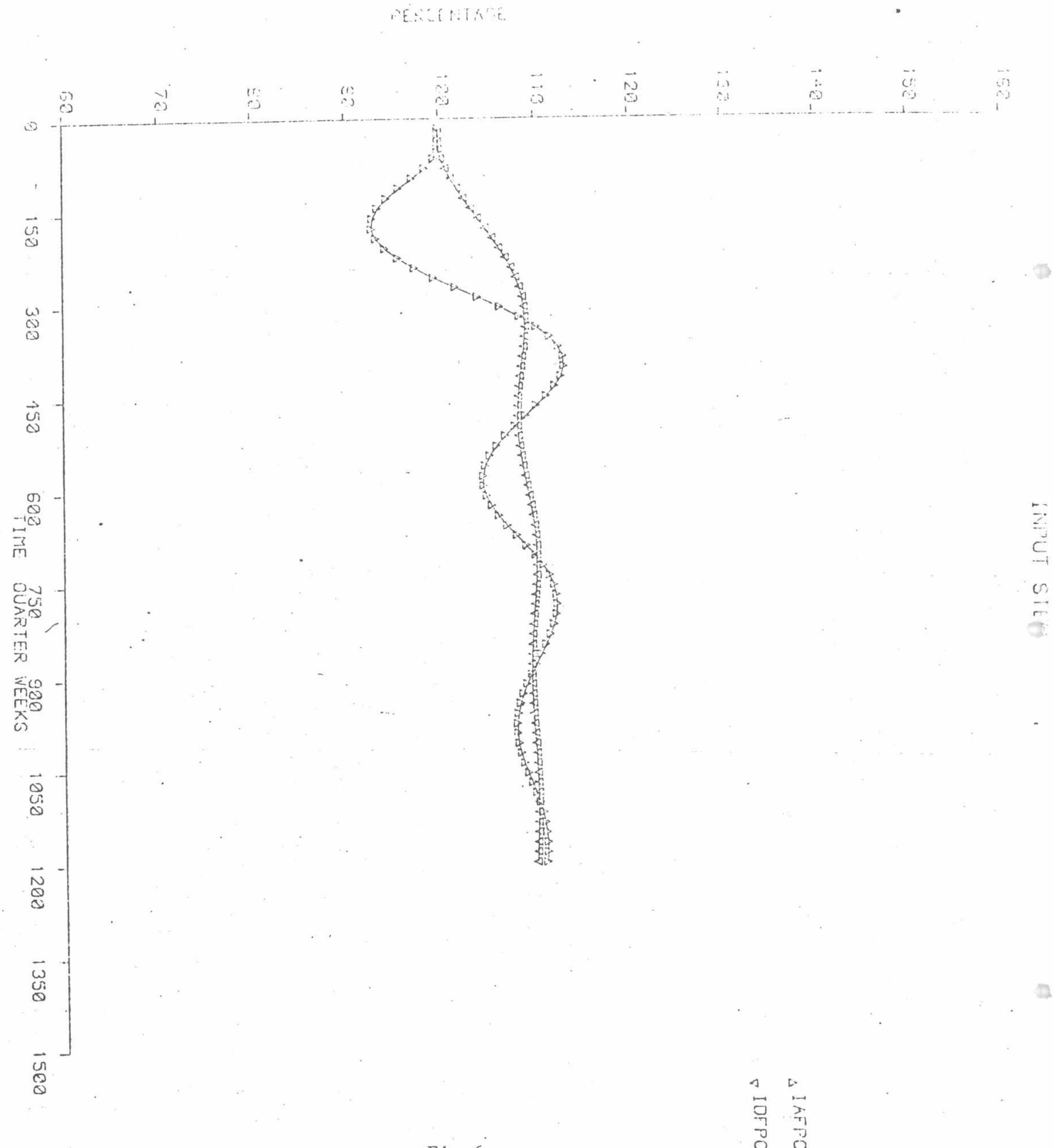
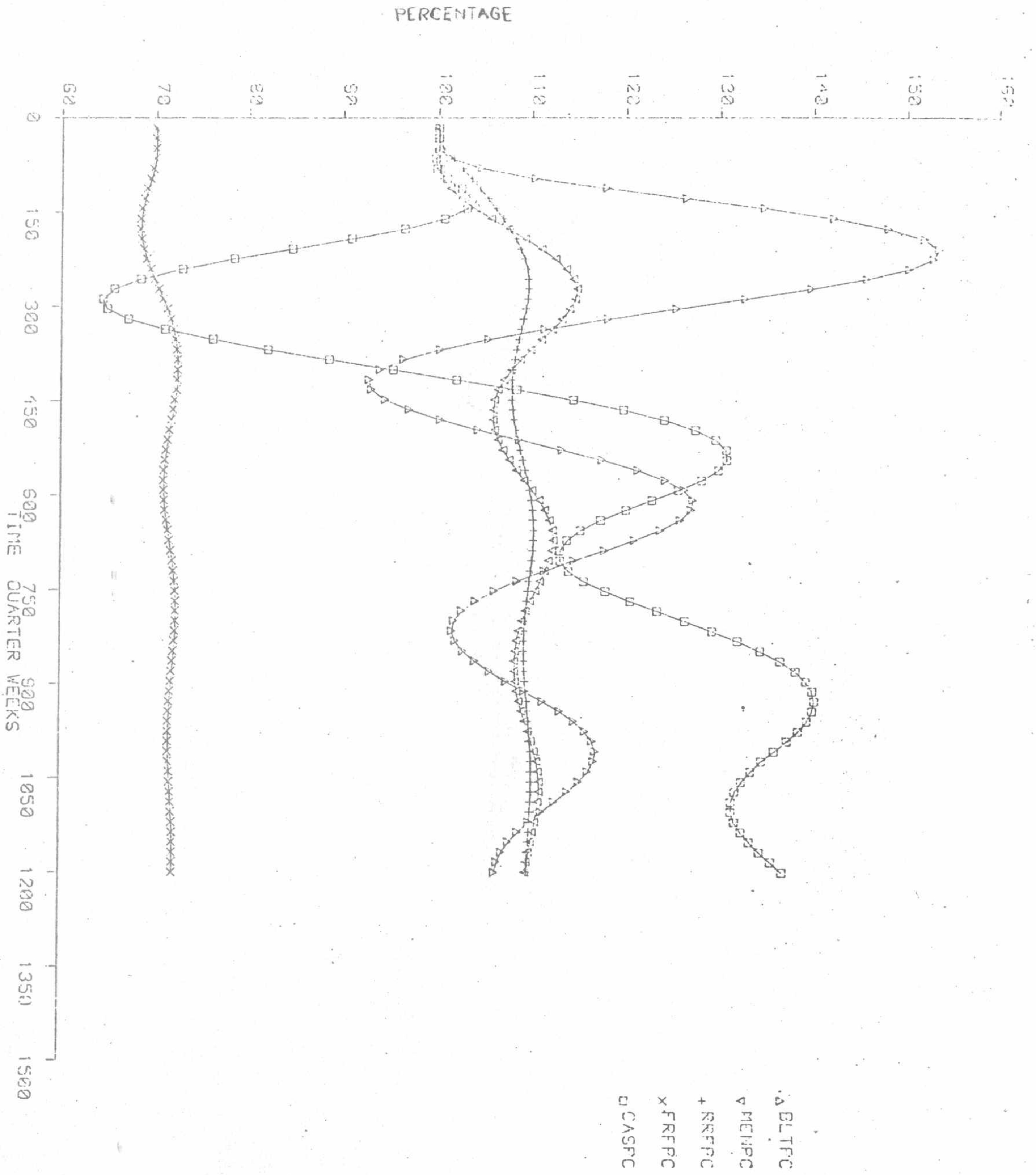


Fig.6.

IAFPC :Inventory actual at factory in percentage of initial value.
IDFPC :Inventory desired at factory in percentage of initial value.



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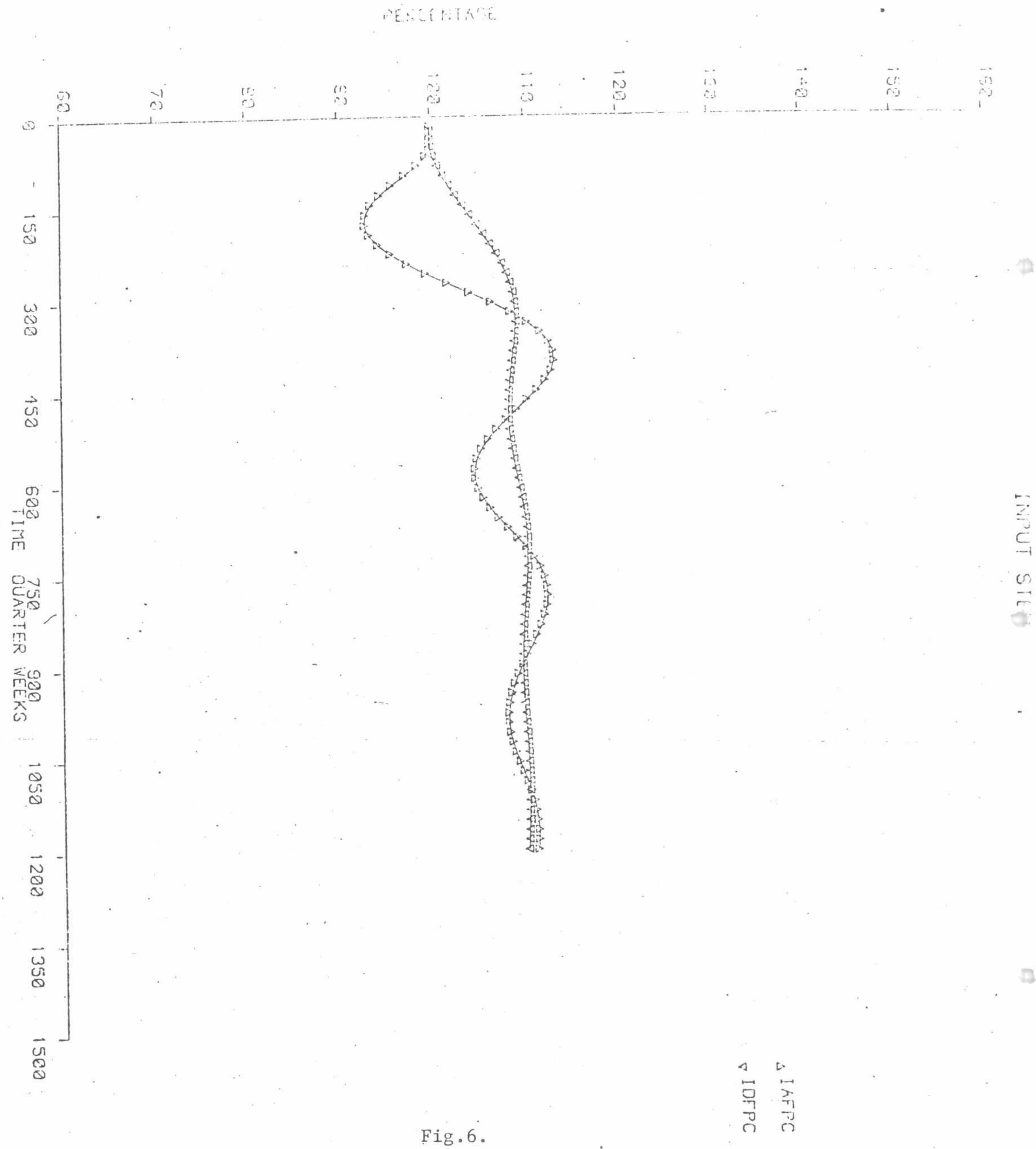

Fig.6.

IAFPC :Inventory actual at factory in percentage of initial value.
IDFPC :Inventory desired at factory in percentage of initial value.

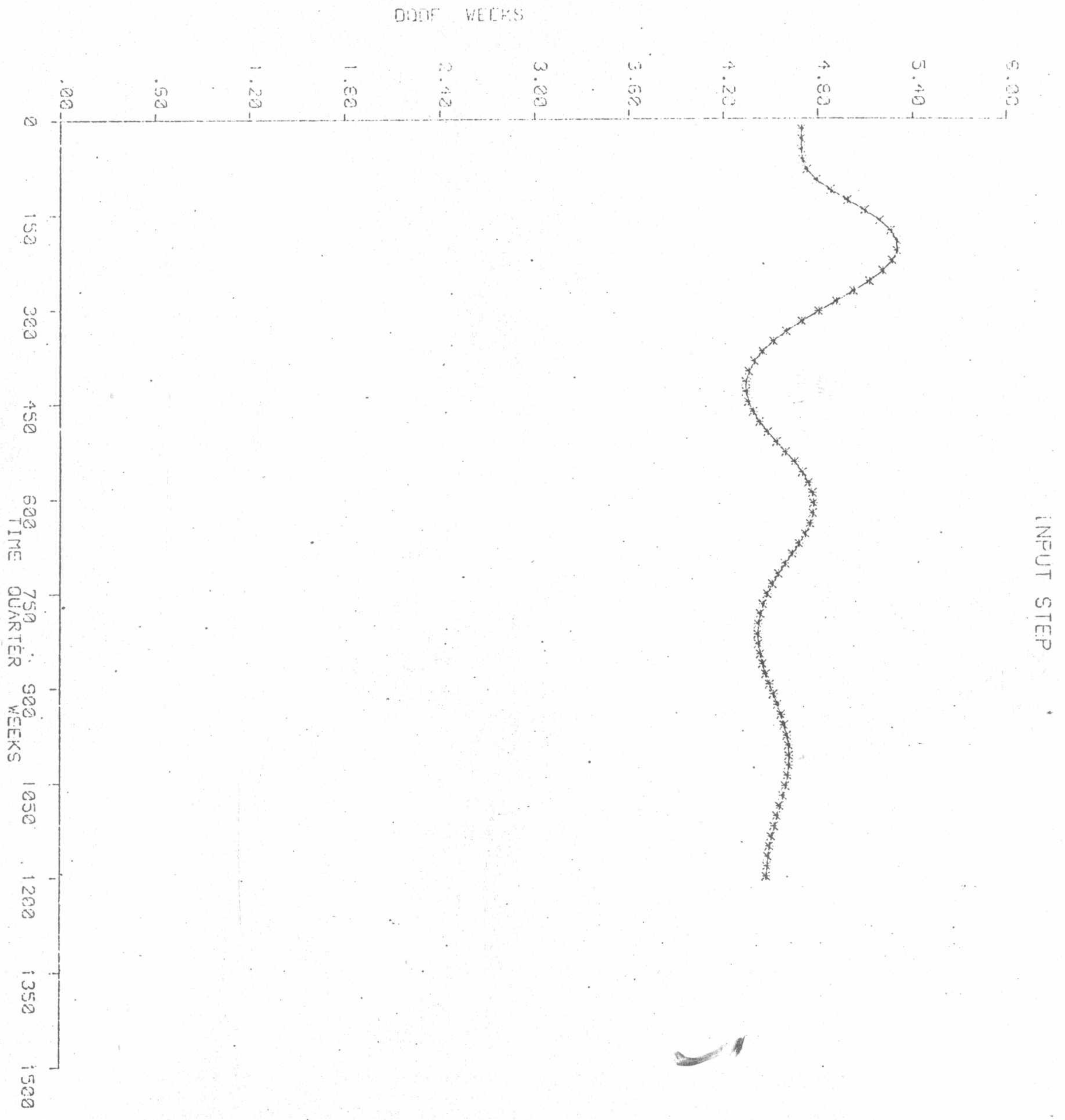

Fig.7.
DQDF:Delay in quoted delivery at factory in weeks.

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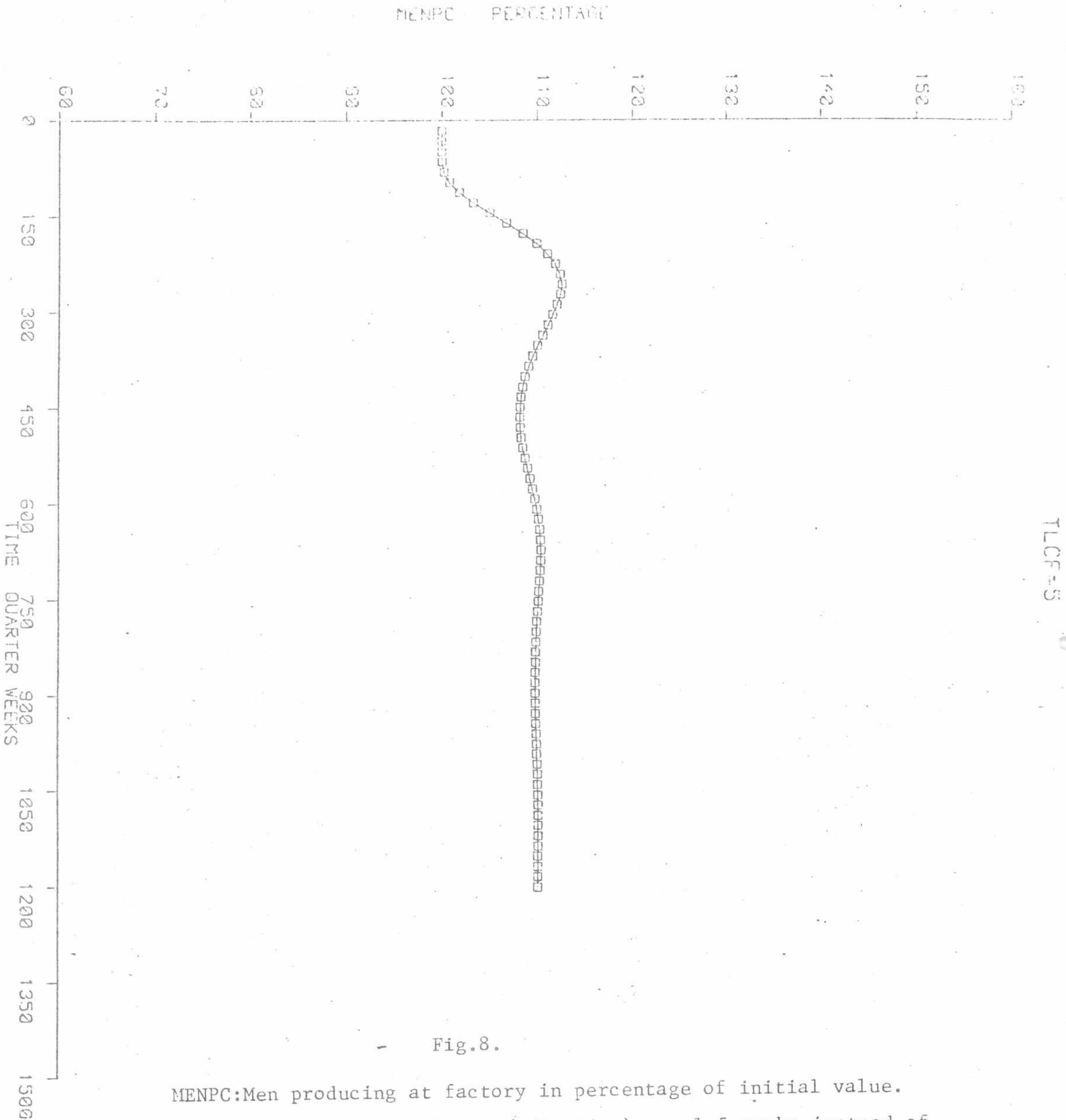

Fig.8.

MENPC:Men producing at factory in percentage of initial value.

TLCF:Time for labour change (adjusting) equal 5 weeks instead of initial value 10 weeks.

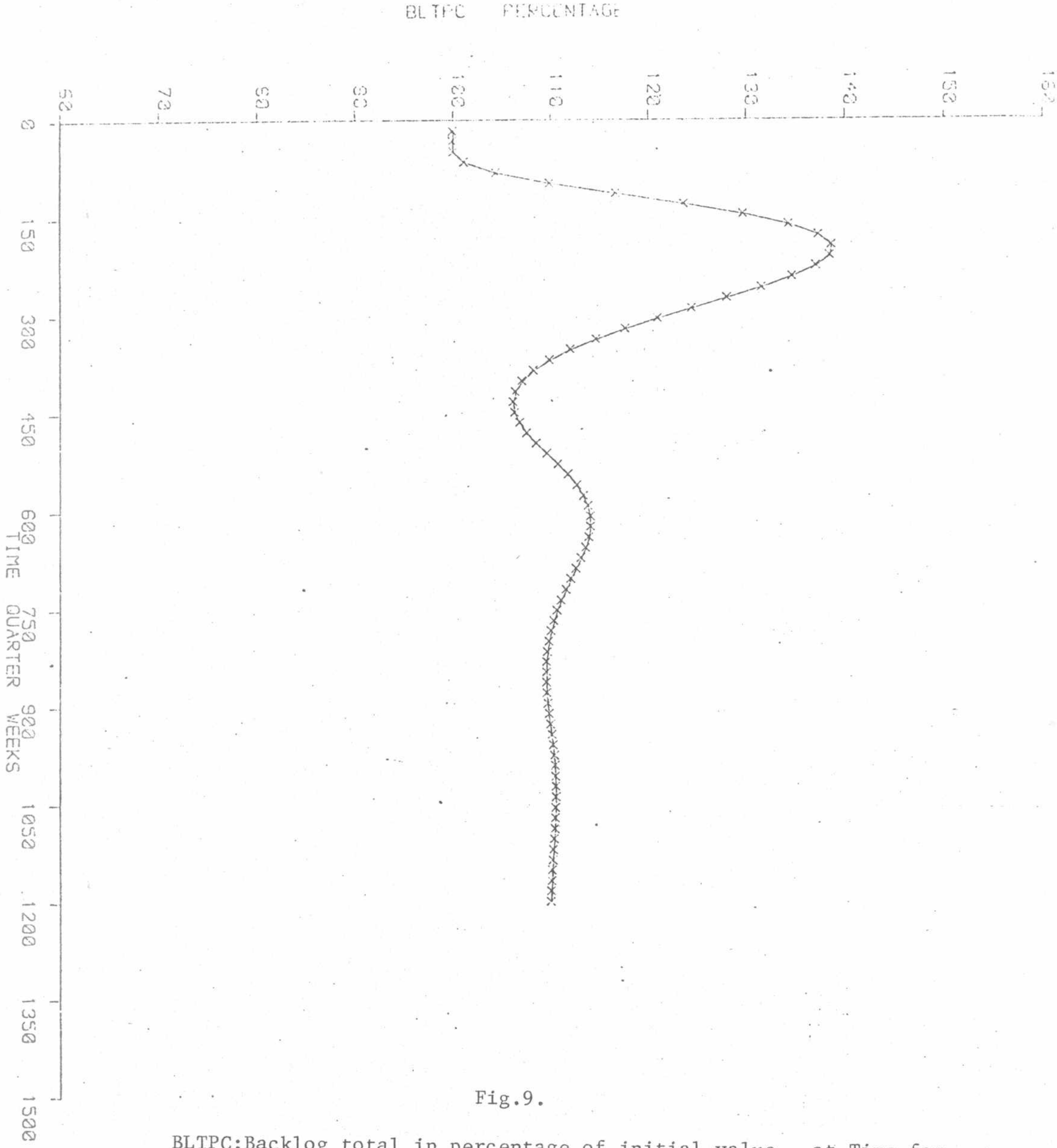

Fig.9.

BLTPC:Backlog total in percentage of initial value , at Time for labour change "TLCF" equal 5 weeks instead of 10 weeks.