Eng. Research Bull.
Faculty of Eng. & Tech.
Menoufia University
Vol. VII. Part 1 , 1985

A MECHANICAL TONG GRIPPER FOR INDUSTRIAL ROBOTS FORCE ANALYSIS AND DESIGN CHARTS

M . Fattouh
Assistant Prof.,
Prod. Eng. & Mach. Design Dept., Faculty of Eng. & Tech.,
Menoufia Univ., Shebin El-Kom, Egypt.

ABSTRACT

This paper presents a simple force analysis of a mechanical tong gripper which is attached to the wrist of an industrial robot. Results, which are in explicit analytical expressions in terms of force ratio, all the kinematic diamensions and the workpiece diameter, are used for constructing a set of design charts. Furthermore, the results can be converted to a computer-aided design technique.

INTRODUCTION

The hand, or end effector, of a robot is usually a gripper or special-purpose tool; it is a specially selected device attached to the wrist of an industrial robot. Figures (1 a-e) show some kinds of the mechanical tong grippers [1]. In this paper attention is foucsed on the tong gripper unit Fig. (1 e).

The ratio, between gripping force and driving force, of a robot gripper represents the main design criterion of such mechanism, because it controls the performance of the robot gripper regarding the safe holding of the workpiece during its movement.

The classical procedure used to determine the kinematic dimension of the tong gripper was only based on the diameter of the workpiece. This was usually done by a schematic drawing of the workpiece and the corresponding suitable kinematic dimensions of the gripper unit considering the technological process and its requirements. Although the preliminary dimensions obtained by this technique gives a relatively practical force ratio, it is obviously not the desired one. In fact, the gripper force ratio depends not only on the kinematic dimensions of the mechanism but also on the driven displacement. Accordingly, the determination of the analytical relation between the force ratio and those dimensions will provide a rigorous matematical bases of the tong gripper. By the analysis of such relation, the lightest possible design of a gripper mechanism will be available. This design must be satisfy the predetermined requirements, the range of the force ratio and the diameter of the workpiece to be clamped, and gives a lightest possible gripper which means volume reduction and inturn lower cost of materials, handling, and shipping.

To synthesize a robot hand for a predetermined mechanism may become an optimization problem. One may solve this problem by optimizing all of the parameters at the same time. But one may solve the problem in an atternative way : study the effects of link parameters on the structure of the robot hand first, then use the results to arrive at the optimal value of the link parameters. In this way, one may reduce the number of parameters in the final optimization problem and may simplify the original problem significantly.

The method presented here pinpoints the kinematic dimensions that will permit the lightest possible design of a mechanical tong gripper for industrial robot while still meeting the desiered force ratio of the gripper.

BASIC RELATIONSHIP

Figure (2) shows a schematic diagram for a tong gripper mechanism with its kinematic dimensions.

First the gripper unit is dismembered and a separate free-body diagram is drawn for each member. These diagrams are arranged in their approximate relative positions to aid in keeping tract of the common forces of interaction Fig. (3). The two-force members 2 and 3 exert forces of equal magnitude $F_A = F_B$ on the connections at the sliding element 1. Equlibrium of the sliding element gives :

$$F_A = F_B = \frac{F_d}{2 \cos \phi}$$

Because of symmetry only one of the two hinged members 4 or 5 can be analysed. The upper hinged member is chosen. Since member 2 is a two-force member, boththe direction and magnitude of the force at I on the hinged member 4 can easily be known. The claw of the gripper (remote-action actuator) debelops a gripping force F_g as a result of the driving force F_d (tension force in the control rod). Because the direction and magnitude of the gripping force F_g are known the direction and magnitude of the force at II on the hinged member 4 can hence be determined. From the free-body diagram of the upper hinged member, the equilibrium of moment about III can be expressed as :

$$F_B . \sin(\phi - \theta) . b - F_g . \cos(180 - \alpha - \theta) . C = 0 \qquad (1)$$

Solving for F_g/F_d gives

$$F_g/F_d = \frac{b . \sin(\phi - \theta)}{2C . \cos(180 - \alpha - \theta) . \cos \phi} \qquad (2)$$

From the geometry of Fig. (2) ϕ and θ can be written as

$$\phi = 180 - [\cos^{-1}\left(\frac{L^2 - b^2 + (F/2)^2 + X_d^2}{2L\sqrt{(F/2)^2 + X_d^2}}\right) + \tan^{-1}\frac{F}{2X_d}] \qquad (3)$$

$$\theta = \cos^{-1}\left[\frac{b^2-L^2+(F/2)^2+X_d^2}{2b\sqrt{(F/2)^2+X_d^2}}\right]-\tan^{-1}\frac{F}{2X_d} \qquad (4)$$

where; $d - e = F$, and $\frac{L}{b} = \lambda$.

It can be realized that the workpiece diameter d_w is not included in Eqn. (3 or 4). Therefore, it is necessary to determine another relationship between d_w. From Fig.(2), θ can be rewritten as :

$$\theta = 180 - \alpha + \sin^{-1}\frac{d_w - d}{2C} \qquad (5)$$

where : $d/C = \lambda_1$

Hence, Eqn.(2) relates the force ratio to all the kinematic dimensions of the gripper unit.

DESIGN CHARTS CONSTRUCTION

To obtain the required force ratio with the possible minimum kinematic dimensions, a designer should combine between the values of λ, C, λ_1, L, F, α and X_d. However, the combination process necessitates a numerous trials which is a waste of time and it may not give the required force ratio with the possible minimum dimensions. Consequently, the idea of representing Eqns. (3-5) in a set of design charts is to determine all parameters that give the desired force ratio with possible minimum dimensions. In these design charts it is considered that those parameters have different values in order to be widely applicable. Figures (4-6) show some of these design charts. Figure (4 a) represents the relation between d_w and θ for different C, λ_1 and for different λ and F at L = 120 mm. Furthermore, Fig. (4 c) shows th relation between X_d and ϕ for the same λ's, F's and L.

To explain how to use the above design chart let us assume that a tong gripper unit is to be designed, with possible minimum dimensions, for an industrial robot with a force ratio ($1.3 \leq \frac{F_g}{F_d} \leq 1.6$) and a workpiece diameter $d_w = 70$ mm.

From Fig. (4 a) it can be seen that for the given d_w (70 mm) a designer can have various values of θ, depending on λ_1 and $\dot{C}$ at $\alpha = 135°$ (in our case there are 6 values from point 1 through 6). Constructing horizontal lines from points (1 through 6 in Fig. (4 a), intersecting the curves in Fig. (4 b), one can find more than one value of X_d depending on λ and F at L = 120 mm for each point in Fig. (4 a). For instance, point 1 in Fig. (4 a) will gives 5 different values of X_d in Fig. (4 b)(11, 12, 13, 14 and 15). Finally each value of X_d in Fig. (4 b) will give one value of ϕ by constructing vertical lines from points (11, 12, 13, 14 and 15) to meet the ($\phi - X_d$) curves in Fig. (4 c). For instance, point (11) in Fig. (4 b) will produce one value of ϕ (point 11 in Fig. (4 c) according to the value of λ and F at L = 120 mm.

Now, by knowing the different parameters given in Eqn. (2) above (α , c, θ, b and ϕ), F_g/F_d can be obtained for all the possible trials. Table (1) is an example showing the design parameters of the different trials obtained for point 1 in Fig. (4 a). It is fairly obvious to refuse trails (13 and 15) because they does not satisfy the requirement. Although trials (11, 12 and 14) give F_g/F_d in the required range trails (12 and 14) give drive displacement larger than that given in trail (11). Therefore, trail (11) should be chosen because it gives not only F_g/F_d in the desired range but also it gives the possible minimum drive displacement (X_d).

Table (1)

Trail		11	12	13	14	15
α	°			135		
C	mm			55		
λ_1	-			1,6		
d	mm			34		
θ	°			54		
λ	-	1	1	1.2	1	1.2
X_d	mm	45	46	124	135	142
L	mm			120		
F	mm	40	40	40	10	10
b	mm	100	100	83	100	83
ϕ	°	77	104	124	123	135
F_g/F_d	-	1.6	2.9	1.27	1.57	1.06

F_d Tension.
F_d Comp.

This procedure should be repeated for all the points in Fig. (4 a) then tabulated and finally the suitable trail that gives F_g/F_d in the required range with minimum drive diqplacement can be selected. It is important to know that this procedure can be repeated for all possible design charts. It would be better and time saving to use Eqns. (2,3 and 5) in form of a computer-aided design technique.

CONCLUSION

A simple force analysis of a mechanical tong gripper which attached to the wirst an industrial robot was made and converted to a design charts.

REFERENCE

1] Volmer, J. Industrie roboter, VEB verlag Technik,
Berlin, 1981.

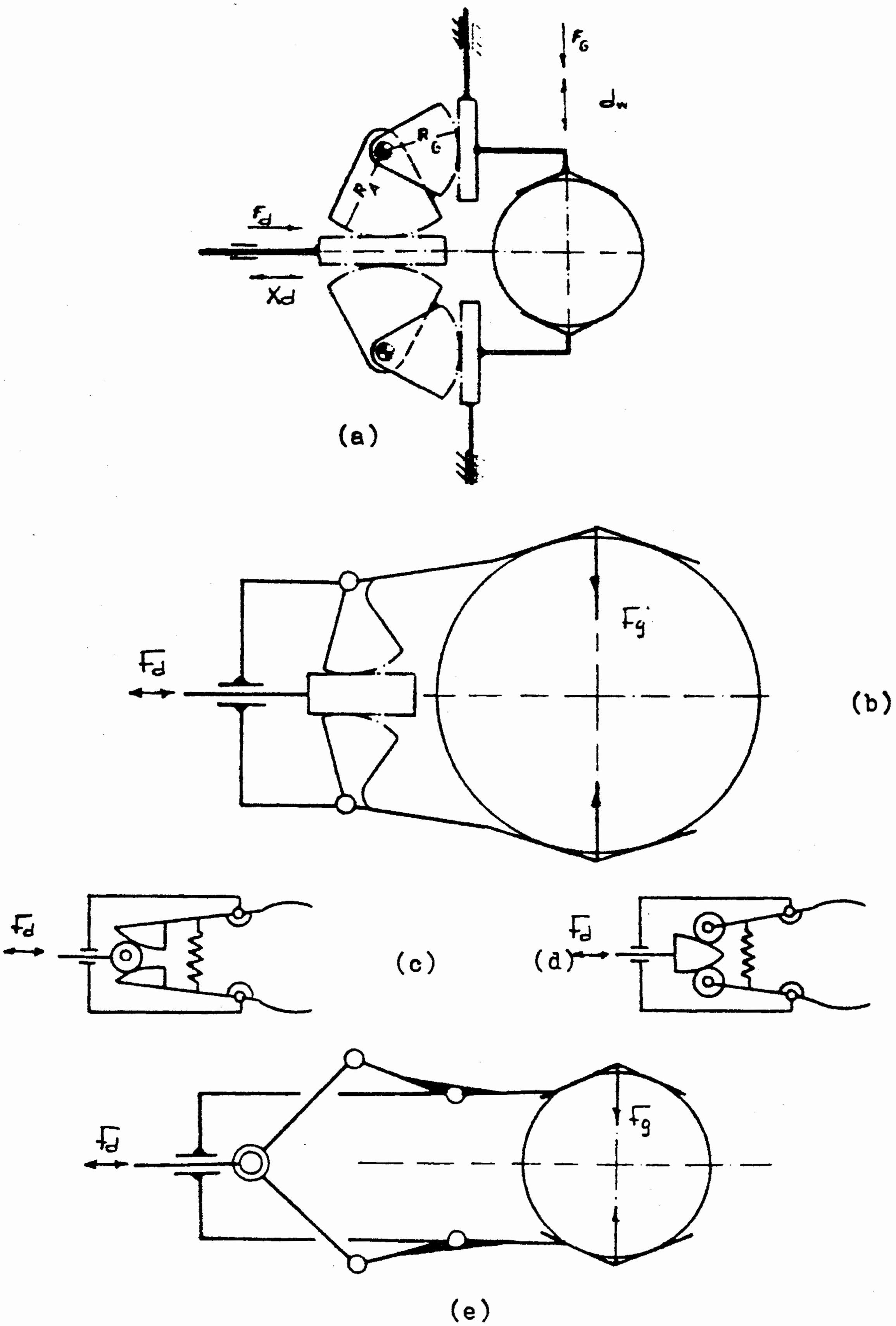

Fig.(1) Some Kinds of the Tong Grippers.

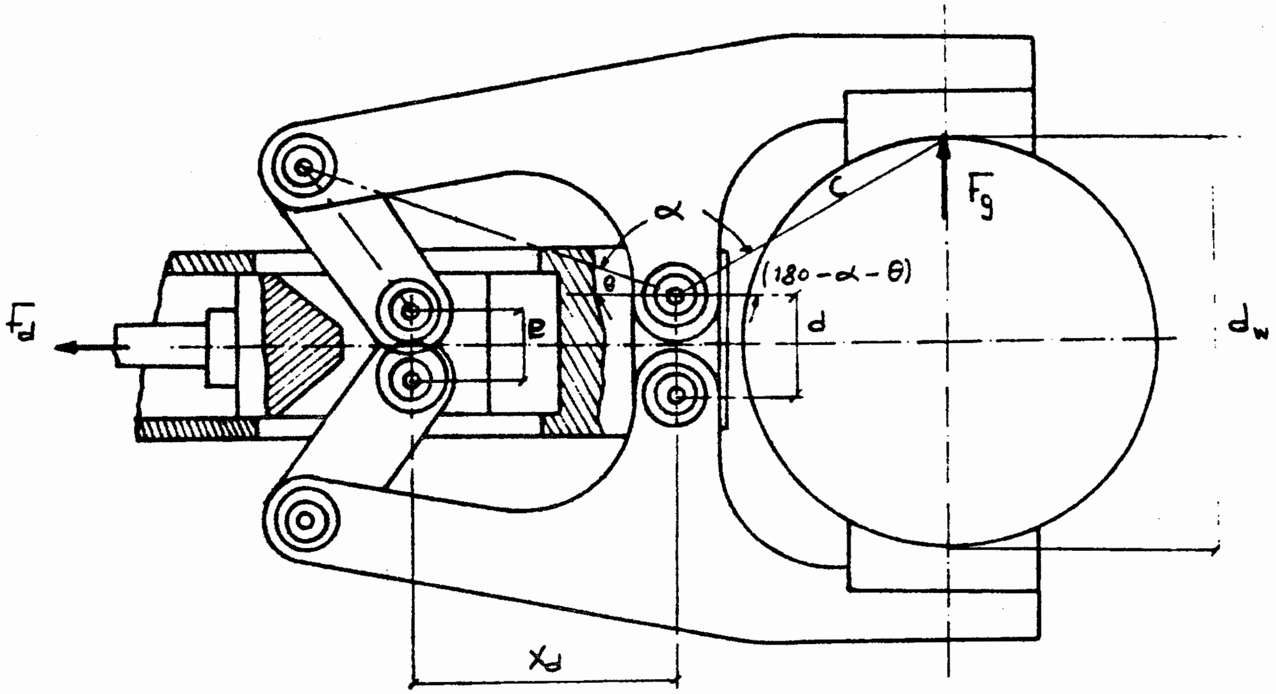

Fig.(2) Schematic Diagram for a Tong Gripper Unit.

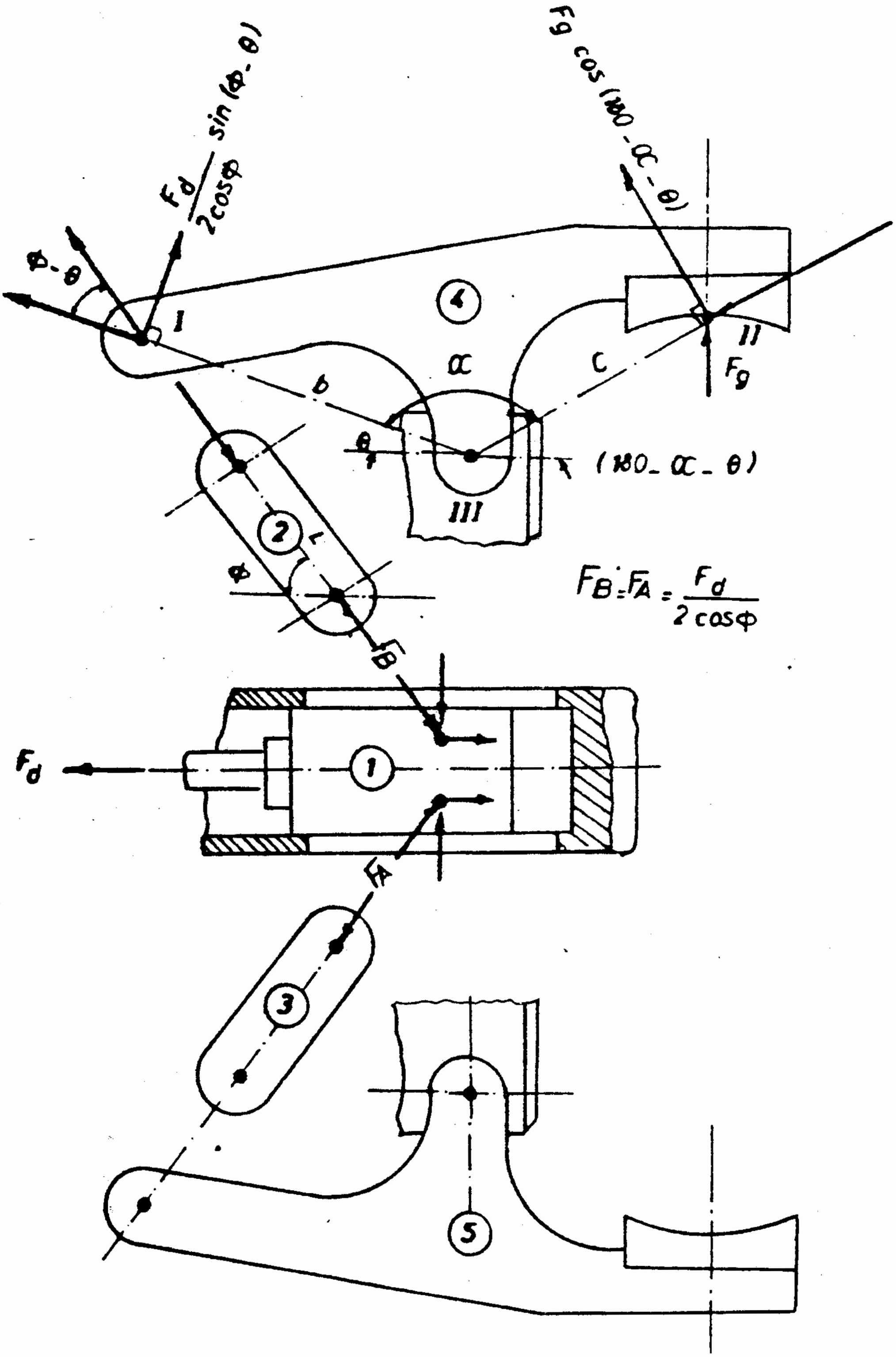

Fig.(3) Free-Body Diagram of the Tong Gripper

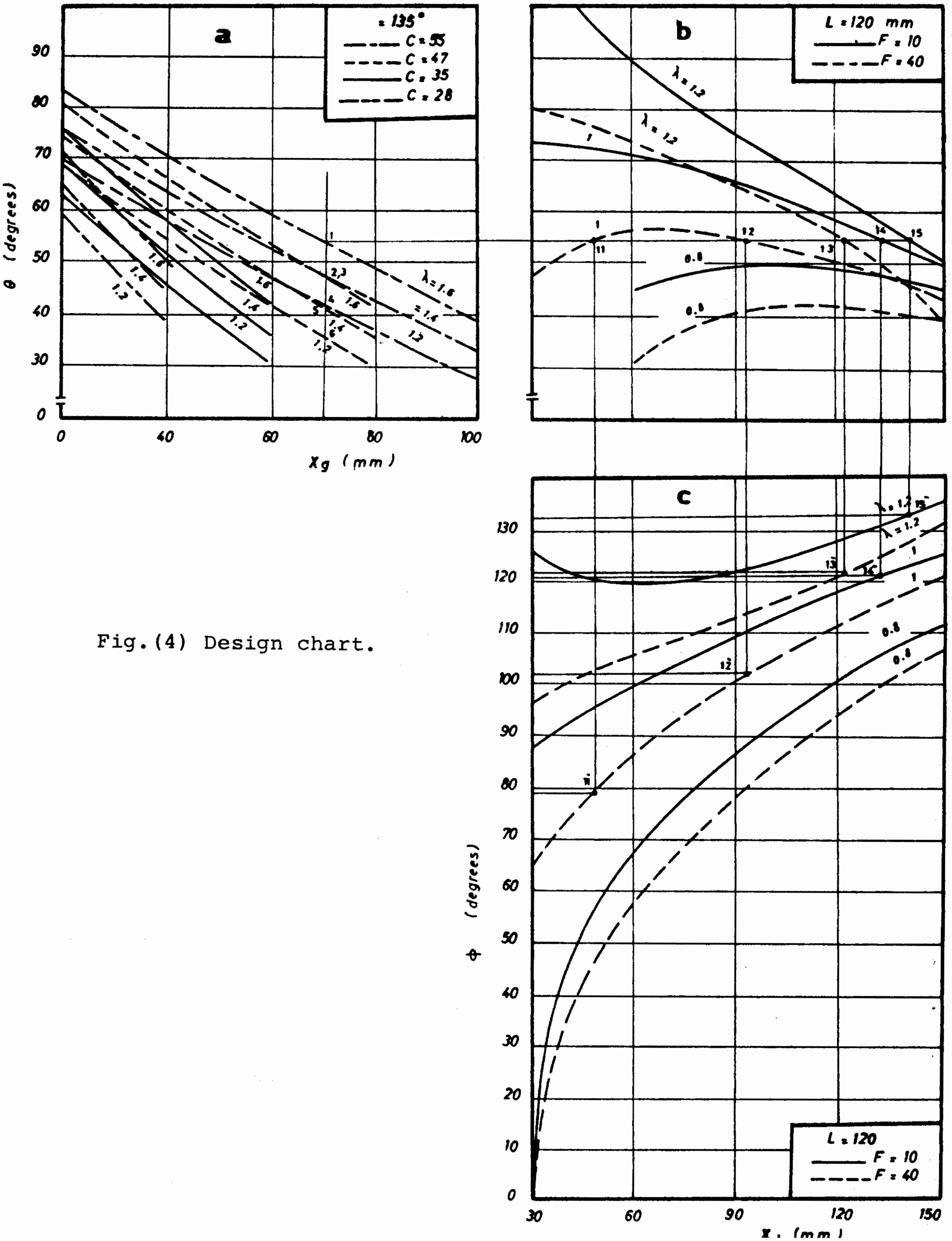

Fig.(4) Design chart.

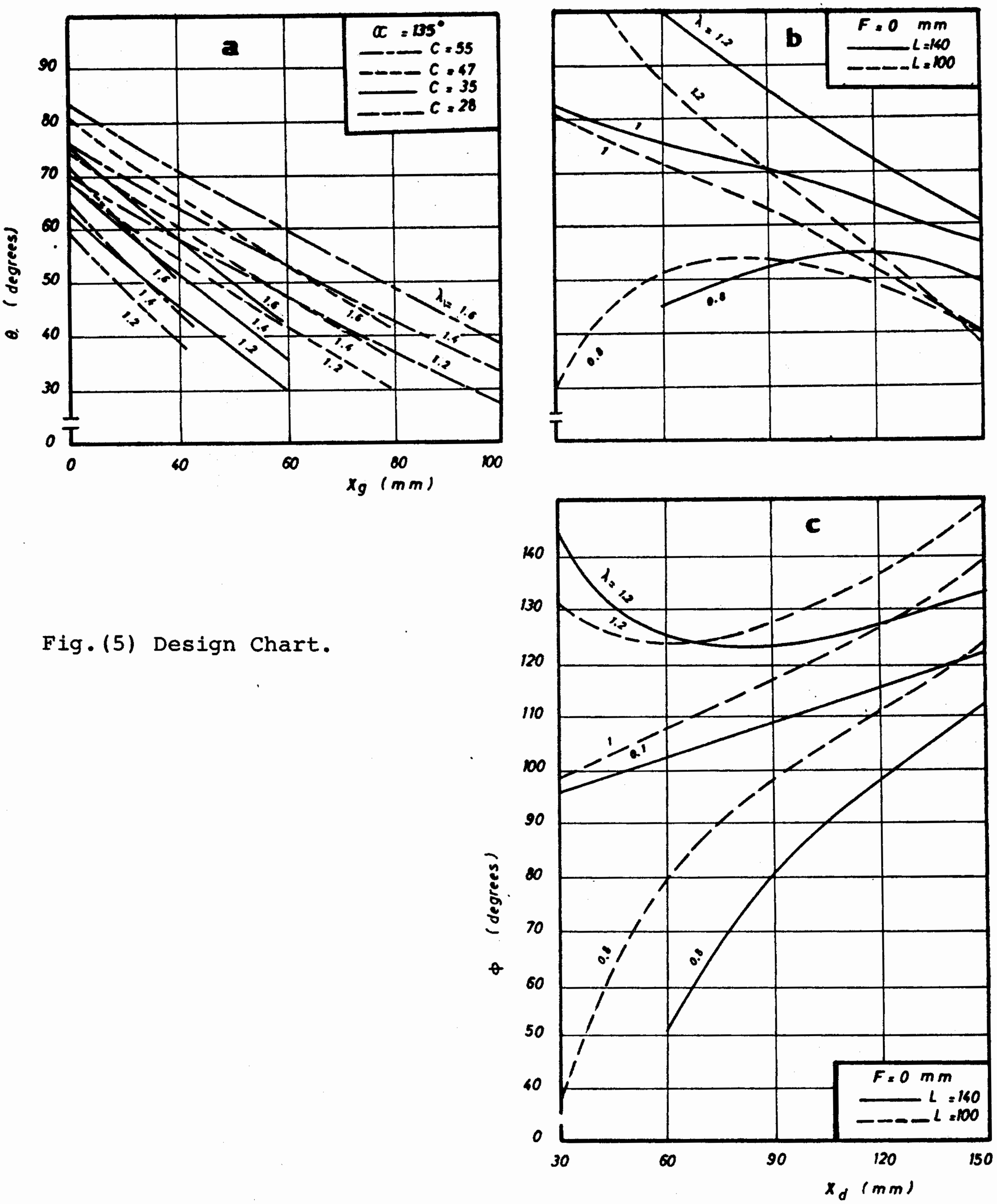

Fig.(5) Design Chart.

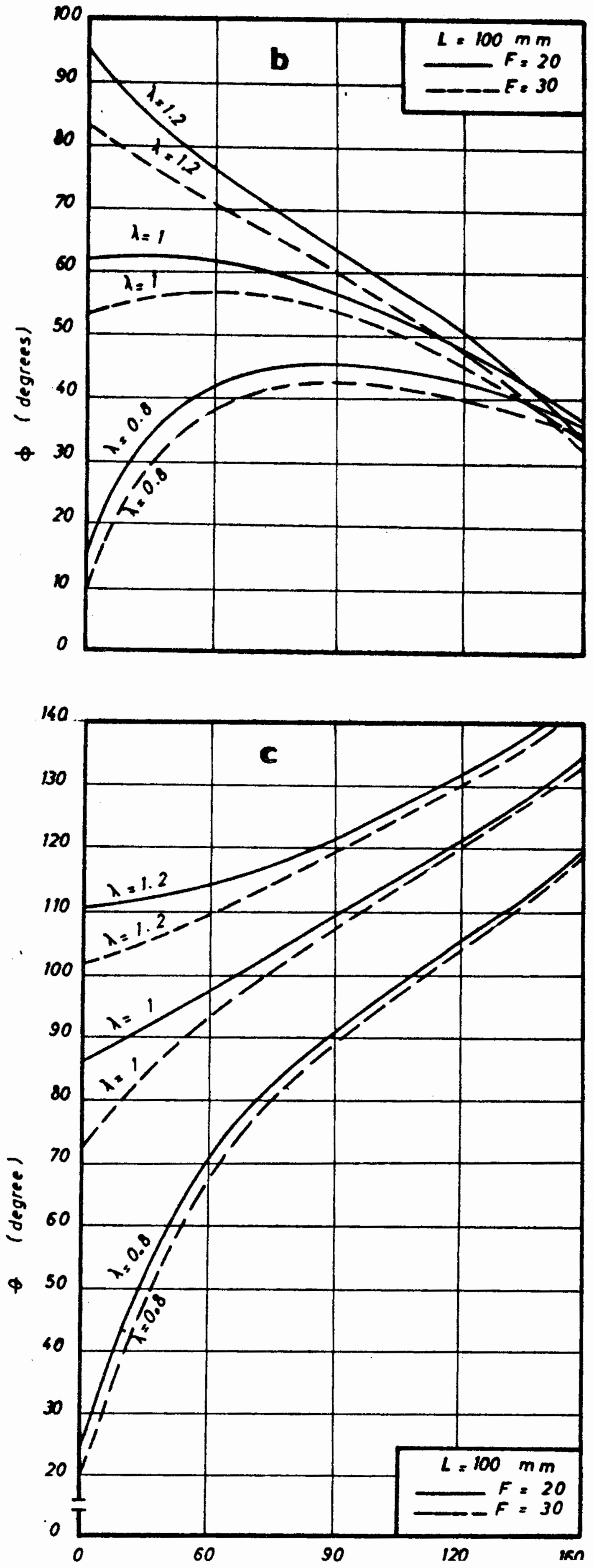

Fig. (6)
Design chart.