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# OPTIMUM DESIGN OF TORSION ROD FOR SULZER WEAVING MACHINE

# التصميم الأمثل لعمود الألتواء لماكينات نسيج سولزر

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## الخلاصة

يعتبر عمود الألتواء لماكينات النسيج سولزر واحد من الأجزاء الرنيسية الهامة بالماكينة ليس فقط من الناحيتين التقنية والوظيفية ولكن أيضا من ناحية المقارنة بين تكلفة إعادة تصميم وإنتاج العمود من خامات محلية أو الشراء من الشركات المنتجة .

هذا وسوف ينعكس التصميم الأمثل لهذا الجزء فى ماكينة النسيج على الإنتاجية ، إستهلاك الطاقة ، ثمن الماكينة و إقتصاديات عملية الإنتاج ككل .

وبالإمكان الحصول على التصميم الأمثل لعمود الألتواء بحل معادلات الحركة الديناميكية لنظام القذف الذى يتضمن عمود الألتواء وذلك بالتوازى مع معادلات التصميم وإستخدام جداول المواصفات القياسية للمواد .

وقد تم الحصول على المعادلة المثالية لأقصى سرعة للمقذوف وهى على صورة:

$$V_{max} = \sqrt{\frac{\phi_{max} \cdot \pi}{16 \cdot K_i}} \quad \sqrt{\frac{\tau_{max}}{m_{min}}} \quad \sqrt{d^3_{max}} \quad \text{m/sec}$$

كما تم الحصول على معادلة مماثلة للطاقة المستهلكة المثالية . وقد إستخدم برنامج كمبيوتر لحل معادلات العوامل متعددة الحدود ذات المتغيرين وذلك لحل معادلات السرعة والطاقة التى لهما متغريين هما طول العمود وقطر العمود .

وقد تم الحصول بواسطة إستخدام برامج كمبيوتر خاصة على تمثيل العلاقات الخاصة بالسرعة والطاقة المستهلكة وطول وقطر العمود بيانيا ورسمها مجسمة فى ثلاثة أبعاد . وعموما فقد وجد أن النسبة بين طول العمود (L) وقطره (d) أى L/d لهما أهمية كبيرة بالنسبة لسرعة الماكينة (أى سرعة المقذوف) – والطاقة المستهلكة . فمع نقص النسبة L/d تزداد سرعة الماكينة والإنتاجية بينما تقل الطاقة المستهلكة مع زيادة النسبة L/d ومن ثم توفير الطاقة . بين هذه الحدود يمكن للمصمم إختيار أنسب الظروف لحالتة.

## ABSTRACT

The torsion rod of Sulzer weaving machine is considered one of the main important elements in the machine, not only from it's technical and functional point of view, but also from the view of comparison between the cost of redsigning and

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production of the rod from local materials or purchasing it from the producing companies.

The optimun design of this part in the weaving machine will be reflected on productivity, energy consumption, machine price and the economics of the production process as a whole.

The optimum design of the torsion rod could be obtained by solving the dynamic equations of the picking system, which includes the torsion rod, parallel with design equations, and the use of standard material specification tables.

The optimum equation obtained for maximum projectile speed is in the form of:-

$$V_{max} = \sqrt{\frac{\phi_{max}}{16.ki}}\sqrt{\frac{\tau_{max}}{m_{min}}}\sqrt{d^{3}_{max}} \quad \text{m/sec}$$

A similar equation has been obtained for optimum power consumption.

Acomputer program has been used to solve the factorization of polynomial equations. That, it is to solve the equation of velocity and power which have two variables, rod length, and rod diameter.

The isometric drawing which represents different variable speed, power consumption, length and diameter has been obtained by special computer program.

Generally it was found that the ratio of rod length (L), and rod diameter (d) is of great importance to machine speed, i.e projectile speed and energy consumption.

As the ratio L/d decreases machine speed increases, hence productivity, while energy consumption decreases as L/d increases, hence energy saving. Between these extremes the designer could choose the most suitable condition for his case.

## 1. INTRODUCTION

The purpose of this work is to make an optimum design solution of torsion rod picking system of the Sulzer machine, using criteria obtained from dynamic plus design solutions with which the designer is familiar.

It is not intended that the conclusions reached by optimum design will be capable of limitless extrapolation; but it is considered that sufficient design information will be given to make a preliminary screening of this particular optimum design solution and to difine if there is more experimental work is necessary.

The projectile is picked across the machine using energy derived from the shear strain energy stored in a torsion rod which is twisted a predetermined amount and triggered off to provide the means of propulsion. As the energy available for picking depends on the angular displacement of the free end for a particular design of torsion rod, the strength of the pick is completely independent of the speed of the machine.

Also the energy can be used to attain very high velocities as the mass being projected is very small [1,2,3].

An understanding of the field of economic application of this machine depends on a clear understanding of its dynamics operations, without this mechanical appreciation, certain characteristic limitations will not be recognized, and certain advantageous features will not be recognized, and certain advantageous [4,5] features will not be fully appreciated. Hence, following, the dynamic solution for optimum maximum speed besides the optimum design solution for minimum power transmission range at maximum possible velocity will be useful.

## NOMENCLATURE

| | | |
|---|---|---|
| A | : Picking arm area | mm$^2$ |
| d | : Torsion rod diameter | mm |
| G | : Steel Modulus of rigidity | N/m$^2$ |
| Io | : Moment of inertia | N.m$^2$ |
| J | : Polar moment of inertia | m$^4$ |
| K | : Mean torque gradient | N.m/rad |
| Ki | : Stress increase factor | ----- |
| L | : Torsion bar length | mm |
| l, | : Picking arm length | m |
| $m_1$,$m_2$ | : Projectile mass, picking arm mass | kg |
| m | : Tatal mass = $m_1 + (m_2 / 3)$ | kg |
| N | : Factor of safety | --- |
| P | : Projectile force | N |
| Sty | : Yield strength | N/m$^2$ |
| Se | : Fatigue strength | N/m$^2$ |
| T | : Applied torque | N.m |
| t | : Time | sec. |
| U | : Power transmitted | N.m/sec. |

| | | |
|---|---|---|
| $V$ | : Projectile linear velocity | m/sec |
| $W_1, W_2$ | : Projectile and picking arm weight | kg |
| $W_{a1}$ | : Aluminum weight of picking arm | kg |
| X1 | : Axis represnts diameter. | |
| X2 | : Axis represents length . | |
| $\theta$ | : Twisting angle | rad |
| $\rho$ | : Density | kg/mm$^3$ |
| $\tau$ | : Maximum shear stress | N/m$^2$ |
| $\phi, \phi_0$ | : Twisting angle, Maximum twisting angle | rad |
| $\Phi$ | : Augular acceleration | rad/sec$^2$ |
| $\omega$ | : Angular speed | rad/sec |

## 2. MAXIMUM PROJECTILE VELOCITY IMMEDIATELY AFTER PICKING

Consider a picking arm swinging about torsion bar axis due to applied torque T. If a tangential force acting at a distance "l" produces an angular acceleration $\Phi$, then;

$I_0 \Phi = p.l = T$ ...................................... (1)

The restoring torque of the twisting bar at free end is equal to applied torque. Substitute the values of T and Io

$m\, l^2 \Phi = \{GJ\, (\Phi_0 - \Phi)\} / L$

Hence

$\phi = \dfrac{GJ}{ml^2 L}(\phi_0 - \phi)$ ...................... (2)

Asssume $A^2 = \dfrac{GJ}{ml^2 L}$ ...................... (i)

Substitute (i) into (2)

$\phi + A^2 \phi = A^2 \phi_0$ ......................... (3)

The general solution of last equation is:-

$\phi(t) = a\mathrm{Cos}At + b\mathrm{Sin}At + \phi_0$ ................... (4)

$\Phi\,(t) = -\,Aa\ \mathrm{Sin}\ At + Ab\ \mathrm{Cos}\ At$ .................... (5)

The boundary conditions for this problem are:-

$t = 0$ at $\Phi = 0$ $\Phi = 0$ (6)

Apply the boundary equations in equations (4) and (5)

$a = -\Phi_0$ $\qquad b = 0.0$

Substitute the constants a and b in equation (4)

$$\Phi_{(t)} = \Phi_0 - \Phi_0 \cos At \quad \ldots\ldots\ldots\ldots \quad (6)$$

$$\dot{\Phi}_{(t)} = A\,\Phi_0 \text{ Sin } At \quad \ldots\ldots\ldots\ldots \quad (7)$$

$$\ddot{\Phi}_{(t)} = A^2\,\Phi_0 \cos At \quad \ldots\ldots\ldots\ldots \quad (8)$$

let

$\dot{\Phi}_{(t)} = A\,\Phi_0 \sin At$

For maximum angular velocity let $\sin A_t = 1.0$, hence:-

$\dot{\Phi}_{max} = A\Phi_0$

The maximum linear velocity is:-

$V_{max} = A.\ \Phi_0\ .\ l$

Use equation (i)

$$V_{max} = \Phi_0 \sqrt{\frac{G}{m}} \cdot \sqrt{\frac{J}{L}} \quad \ldots\ldots\ldots\ldots \quad (9)$$

Also the maximum acceleration is

$$\ddot{\Phi}_{max} = A^2\,\Phi_0 \quad \ldots\ldots\ldots\ldots \quad (10)$$

## 3. DISCUSSION OF OPTIMUM PROJECTILE VELOCITY

For torsion rod picking system of Sulzer machine, the primary purpose of a torsion rod is to transmit a torque or transfer energy between picking cam shaft and the picking arm and hence to projctile. For this particular problem, it is required to design a torsion rod picking system which will be subjected to repeated loadings in Sulzer machine where precisely shear strain energy per cycle cannot be predicted.

The desired life for the torsion rod is to be 500 million cycles of repeated load application, which will enable to use the fatigue strength values from table 5 Ref. [6]. The primary design equation will express the picking system velocity at its maximum condition, which is produced after a dynamic analysis of the entire picking system Again rewrite equation (9) to be come:-

$$V_{max} = \Phi_0 \sqrt{\frac{G}{m}} \cdot \sqrt{\frac{J}{L}} \quad \ldots\ldots\ldots\ldots \quad (9)$$

The limit equation on permissible values of the diameter d is

$$d \le d_{max} \quad \ldots\ldots\ldots\ldots \quad (11)$$

The limit equation permissible values of L is again expressed as:

$$L^{min} \le L \le L_{max} \quad \ldots\ldots\ldots\ldots \quad (12)$$

The first subsidiary design equation will express the torque gradient k, a specified functional requirement. It is assumed with reasonable accuracy that the integrated effects of highly localized stress concentration on angular deflection are small and therefore the following equation will be used

$K = \pi d^4 G / 32 L$ ................ (13)

K : is aspecified value

The second subsidiary design equation is for the maximum shearing stress in the torsion rod, since it is limited by the selected criterion for failure.;

$\tau_{max} = Ki\ 16\ T_2 / \pi d^3$ ................ (14)

The third subsidiary design equation is the maximum angular acceleration.;

$$\ddot{\phi} = \frac{GJ}{ml^2 L}\phi_0 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (10)$$

Also the torque is :-

$T_1 = I\ \ddot{\Phi}$ .............. Equ. 1.

Combine eqs. (1) and (14) to find L, then ;

$$L = \frac{GJ\ .\ \phi_0}{\frac{\pi d^3\ \tau_{max}}{16\ ki}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (15)$$

Substitute equ. 15 in equ. 9 to eliminate L, then:-

$$V_{max} = \sqrt{\frac{\phi_0 x \pi}{16\,ki}} . \sqrt{\frac{\tau_{max}}{m}} . \sqrt{d^3} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (16)$$

Hence obviously, $\tau_{max}$ should be placed equal to its upper limit, where

$$\tau\ max \leq \frac{Se}{\left(1 + \frac{Se}{Sy}\right) N} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (17)$$

The developed primary design equation-(16) of ideal maximum velocity, should be writen as:

$$V_{max} = \sqrt{\frac{\phi_{0\,max} . \pi}{16\,ki}} . \sqrt{\frac{\tau_{max}}{m_{min}}} . \sqrt{d^3_{max}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (16.1)$$

## 4. DISCUSSION OF OPTIMUN POWER TRANSMISSION

The shaft of weaving, machine is to transmit a virtually constant torque at a constant maximum angular velocity from, Fig. 1 which is general for many Sulzer machines. The primary design equation from basic mechanics will be. :-

$U = T . \omega$ ...................... (18)

The limit equations can be written as follows:-

$K \geq K_{min}$ (i)

$d < d_{max}$ (ii)

$L_{min} \leq L \leq L_{max}$ (iii)

$\tau_{max} \leq \frac{Sty}{2}$ (iv)

Eliminate T from equation , (18) using equation (14). Also by equation (iv), the primary design equation becomes as follows:-

$$U = \left(\frac{\pi}{32\ Ki}\right)\left(\frac{V_{max}}{\ell}\right).\ Sty\ .\ d^{3} \text{ ............} \qquad (19)$$

Eliminate d from equation (19), using equation (13), thus equation (18) will give ideal minimum power as:-

$$U_{min} = \left(\frac{\pi}{32}\right)^{1/4} \frac{V_{max}}{\ell}\left[\frac{Sty}{G^{3/4}}\right]\left(\frac{1}{Ki}\right)(L_{max}\ k_{min})^{3/4} \text{ ...............} \qquad (20)$$

## 5. COMPUTER PROGRAMS

The computer programs calculations can be divided into two main programs:-

### 5.1- Projectile Velocity Calculations and Discussion

Computer programs had been used to solve factorization of polynomials equation [7] that is to solve the equations of velocities which have two variables, length and diameter

The first program is required to estimate, eq (9) and to draw projectile velocity at the whole range of lengthes, diameters, twisting angles and materials.

Computer programming results, had been plotted in three dimensions Figs.2 where the projectile speed represents the vertical axis Y while the other two axis are illustrated in the folloing table :-

| axes | 1- | 0 | 1 |
|---|---|---|---|
| X1= | $d_{min}$ = 15mm | $d_{mean}$ = 20mm | $d_{max}$ = 25mm |
| X2= | $L_{min}$ = 300mm | $L_{mean}$ = 5000mm | $L_{max}$ = 700 mm |

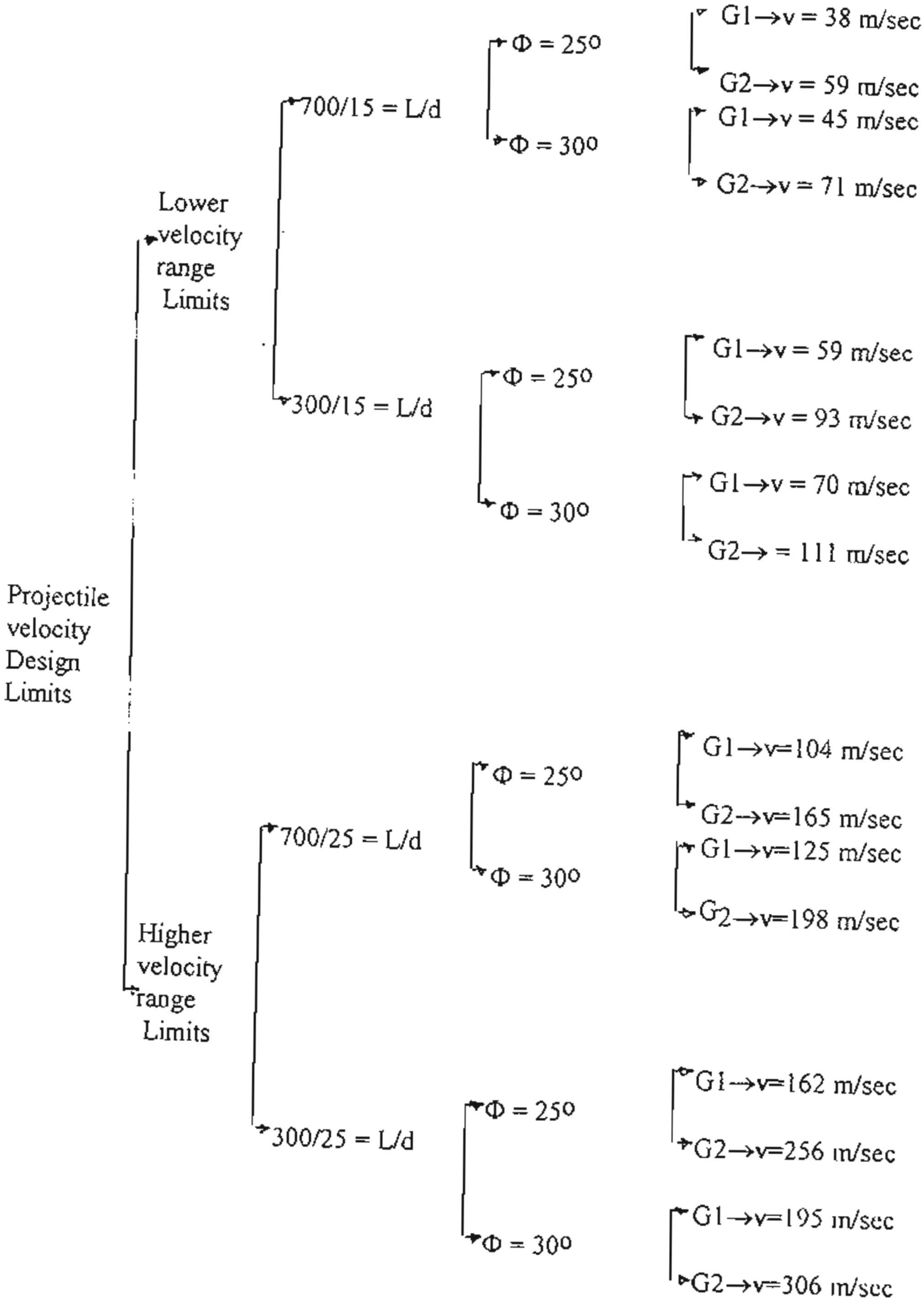
Figs. 2 show the change of projectile velocity versus diameter (d) and length L. These figures are plotted for three cases, the torsion rod plus the picking arm are made from steel, which have modulus of rigidity of 8.45 X $10^{9}$ kp/$m^{2}$ and of 1.4 X $10^{10}$ kp/$m^{2}$. And the third case, the torsion rod is made from steel, which has modulus of rigidity of 1.4 X $10^{10}$ kp/m2, parallel with aluminum picking arm. The privous three cases are plotted at two twisting angles of 25° and of 30° respectively

Figs. 2 (a,c,e,g,i,k) had been sectioned at differrent constant projectile velocity to produce Figs. 2 (b,d,f,h,j,l) in these figures, the designer can choose and define the diameter and length of torsion rod at any required, constant projectile velocity.

Again Figures 2 (a,c,e,g,i,k) has two limits, the first limits are the lower range of projectile velocities. It has L/d ratio between 700/15 for minimum velocity up to 300/15 for higher velocities in the lower range. That is for projectile velocities between 38 m/sec up to 111 m/sec and for different materials and twisting angles.

The second limits, are for higher range of projectile velocities. It has L/d ratio between 700/25 for minimum velocities up to 300/25 for higher velocities. That is for projectile velocities between 104 m/sec. up to 306 m/sec for different materials and twisting angles. These values are illustrated in details in the following flow chart:-

## Flow chart of projectile velocity



For maximum projectile speed requierments, it is necessary to choose L/d ratio of 300/25, with shaft material which has rigidity modulus of 1.4 X $10^{10}$ kp/$m^2$ and Φ $30^o$

## 5.2 POWER CONSUMPTION

The second program calculates eq. (19) and draw the power consumption at the whole range of lengthes, diameters, speeds, twisting angles and materials of the torsion rod. Computer programming results had been plotted in three dimensions Figs. 3 where power Consumption N. represents the vertical axis and the other two axes illustrated in the following table:-

| axes | -1 | 0 | 1 |
|---|---|---|---|
| X1= | dmin = 15mm | dmean = 20mm | dmax = 25mm |
| X2= | Lmin = 300mm | Lmean = 5000mm | Lmax = 700 mm |

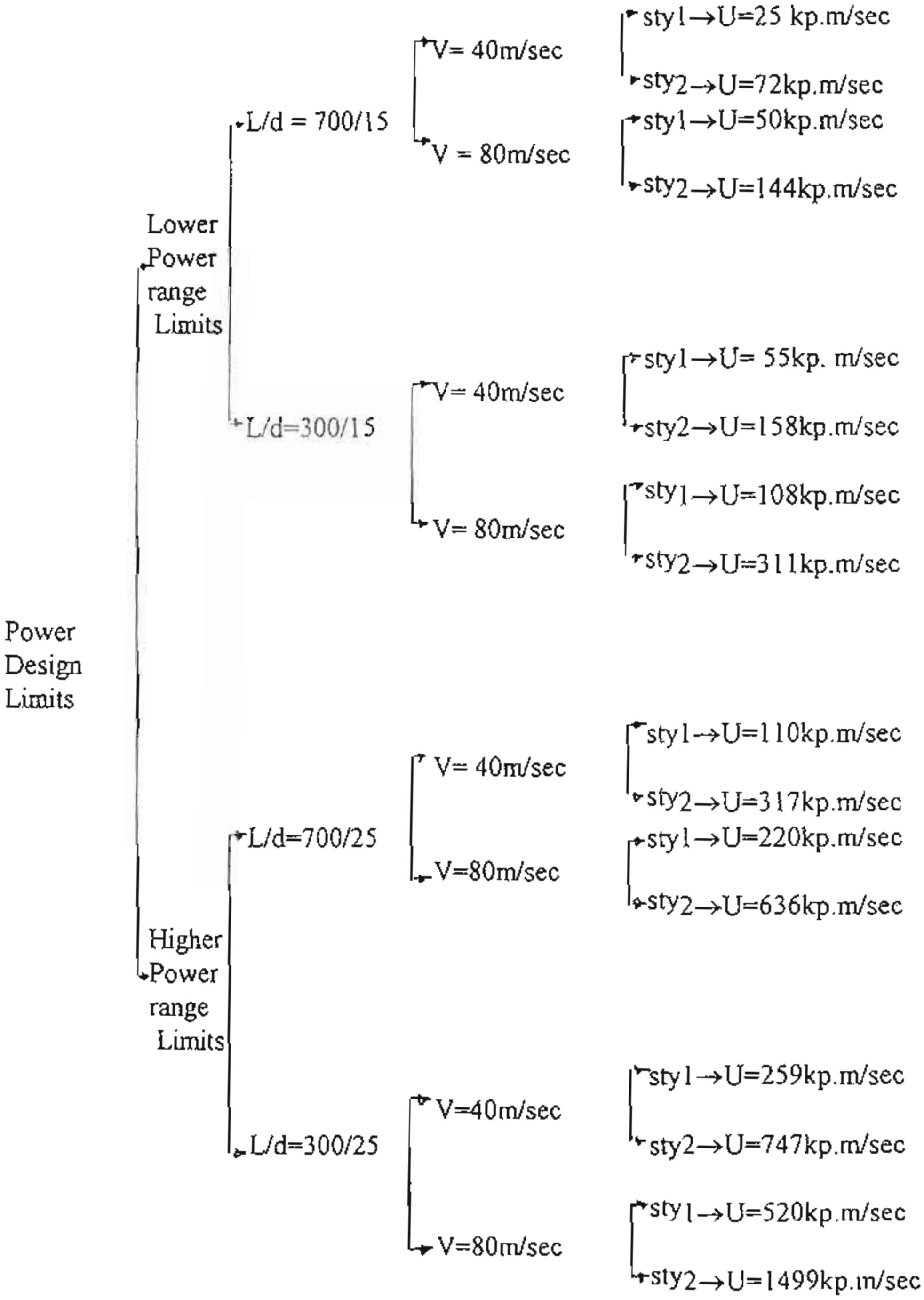
These figures show the change of power consumption versus diamster (d) and length (L), for two materials, the first material has yield strength of 25.4 X $10^6$ kp/$m^2$, the second material has yield strength of 73.2 X $10^6$ kp/$m^2$. The previous two materials were calculated at speeds of 40, 60, 80, m/sec.

Figs 3 (a,c,e,g,i,k) had been sectioned at constant power consumption to produce Figs 3 (b,d,f,h,j,l), from these figures, the designer can choose and define the diameter and the length of the torsion rod at any required constant power consumption.

Again Figures 3 (a,c,e,g,i,k) has two limits, the first limits are the lower range of power consumption. It has L/d ratio between 700/15 for minimum power consumption up to 300/15 for higher power consumption in the lower range. That is for power consumptions between 25 kp.m/sec up to 331 kpm/sec. Also that is for different projectile velocities and materials.

The second limits are for higher range of power consumption. It has L/d ratio between 700/25 for minimum power consumptions up to 300/25 for higher power consumptions. That is for power consumptions between 110 kp.m/sec up to 1499 kp.m/sec for different projectile velocities and materials. These values are illustrated more detail in the following flow chart

**Flow chart of power consumption**



For minimum power consumption requirements, it is necessary to choose L/d ratio 700/15, with shaft material which has yield styength of 25.4 X $10^6$ kp/$m^2$

If the speed of production is more important economically than the price of power consumption saving, then, it is necessary to choose L/d ratio 300/25 with shaft material which has yield sytrength of 73.2 X $10^6$ kp/$m^2$

## 6. CONCLUSIONS

1- Computer programming enables the designer to choose and define the suitable diameter and length of torsion rod at any required maximum projectile velocity or minimum power consumption also to choose the most suitable working condition of the loom.

2- For maximum projectile velocity requirements, it is necessary to choose L/d ratio equal to 300 mm/ 25 mm with shaft material which has rigidity modulus of 1.4 X$10^{10}$ kp/$m^2$ and torsion rod twisting angle of $30^o$.

3- When the speed of production is more important from the economical point of view than the price of power consumption saving, then, it is necessary to choose L/d ratio equal to 300 mm / 25mm, with shaft material which has yield strength of 73.2 X $10^6$ kp/$m^2$.

4- For minimum power consumption requirements, it is necessary to choose L/d ratio 700/15, with shaft material which has yield strength of 25.4 X$10^6$ kp/$m^2$.

5- Very high velocities can be attained as the mass of the projectle and the picking arm mass are very light.

6- Equations in the form of Equs. (9,16.1,20) have been deduced theoretically to calculate the optimum range for the diameter, length of torsion rod and maximum velocity of the projectile at minimum power transmission, and for different materials and twisting angles of torsion rod.

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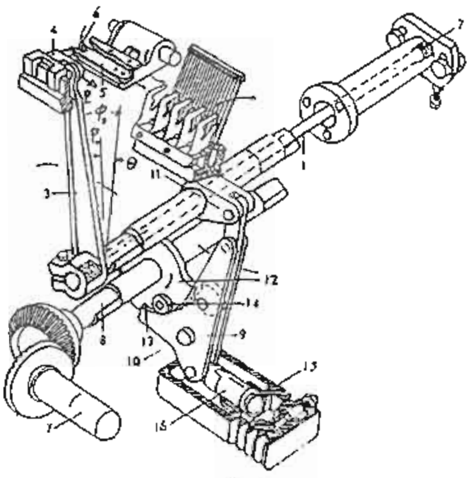


FIG. (1) DRAWING ILLUSTRATING THE TORTION BAR PICKING SYSTEM OF THE SULZER MACHINE

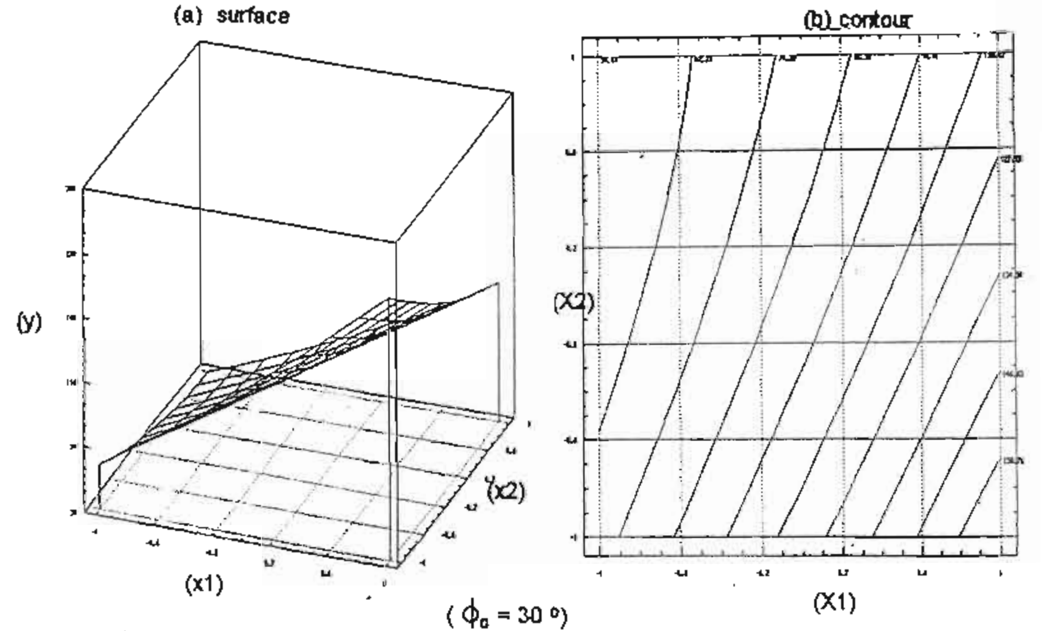
## TORSION BAR PICKING SYSTEM OF THE SULZER MACHINE

The picking arrangement is clearly shown in Fig 1 the torsion bar (1) has its splined end (2) rigidly constrained in an adjustable plate with provision for adjusting the twisting angle and, hence, the gripper projection velocity. The other end of the torsion bar-is splined into the picking arm (3) which carries the picking shoe (4) at its upper extremity. The gripper (5) is shown in the shuttle lifter with the gripper spring opener visible at (6).

The bevel wheel drive (7) rotates the picking cam shaft (8) which carries the picking tappet (12). The pivoted (11) is rigidly connected to the torsion bar, and through a short linkage to the togglle plates (9) centred at (10). The action of the cam is for the small bowl (14) to bear against the toggle (13), rotating it anti-clockwise about center (10), thus withdrawing the picking shoe to its reamost position. The torsion bar is twisted to its maximum $\Phi_0$, and permitting the whole of the shear strain energy to be transmitted instataneously to the gripper.

Fig 2(a-d) : Projectile velocity (Y) versus diameter (X1) and length (X2) of torsion rod ($G_f$ = 8.45 x $10^9$ kp/$m^2$)

($\phi_o$ = 25 °)



( $\phi_o$ = 30 °)

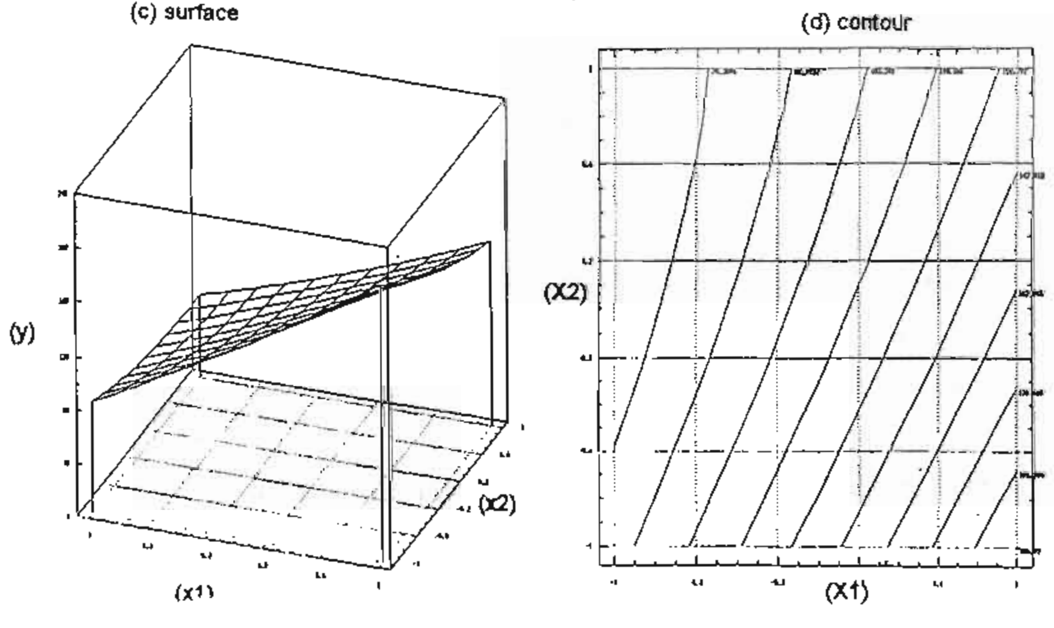
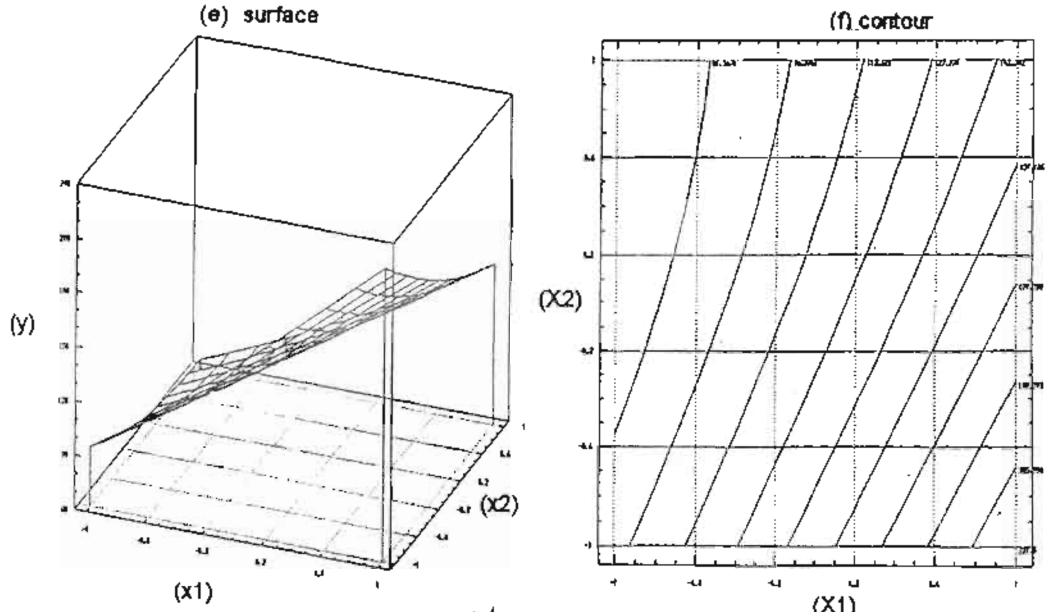


Fig 2(e-h) : Projectile velocity (Y) versus diameter (X1) and length (X2) of torsion rod $(G_1 = 1.4 \times 10^{10}\ kp/m^2)$

$(\phi_o = 25°)$



$(\phi_o = 30°)$

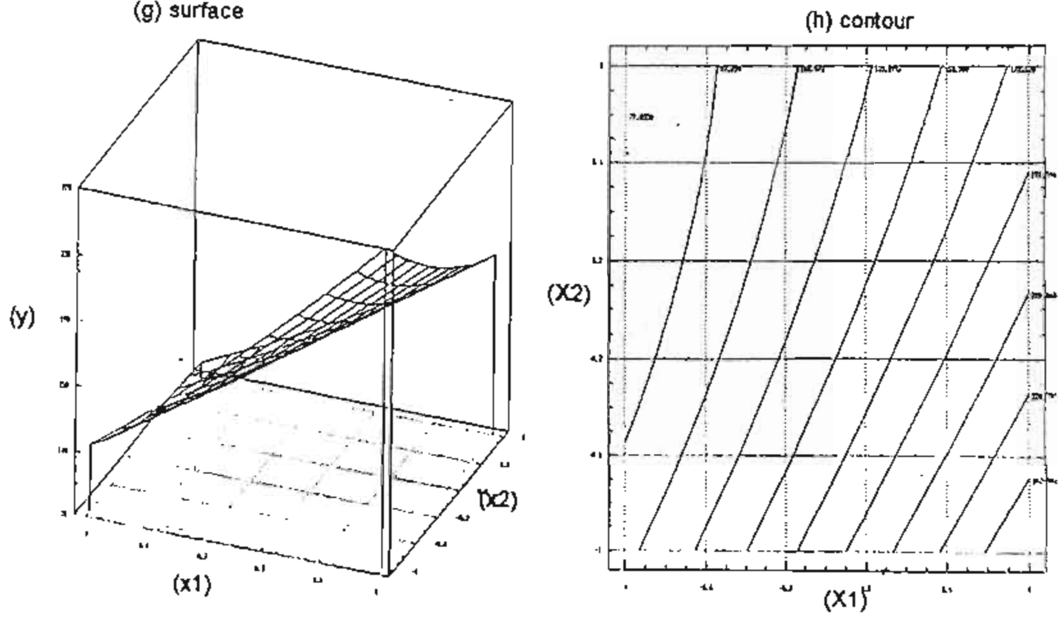
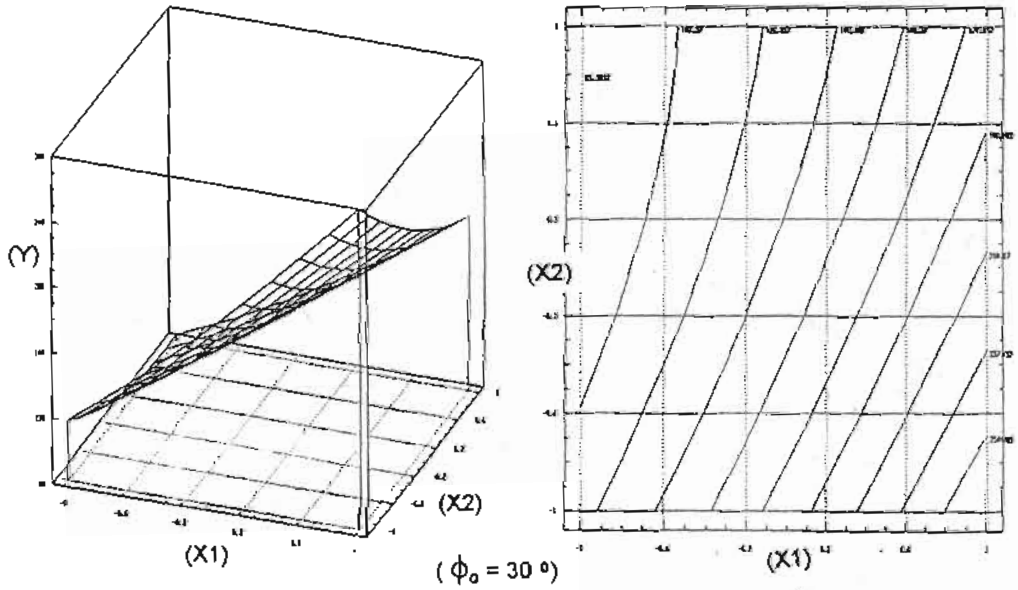


Fig 2(I-l) : Projectile velocity (Y) versus diameter (X1) and length (X2) of torsion rod with aluminum picking arm ($G_1$ = 1.4 x $10^{10}$ kp/$m^2$)

($\phi_o$ = 25 º)

(i) surface

(j) contour



( $\phi_o$ = 30 º)

(k) surface

(l) contour

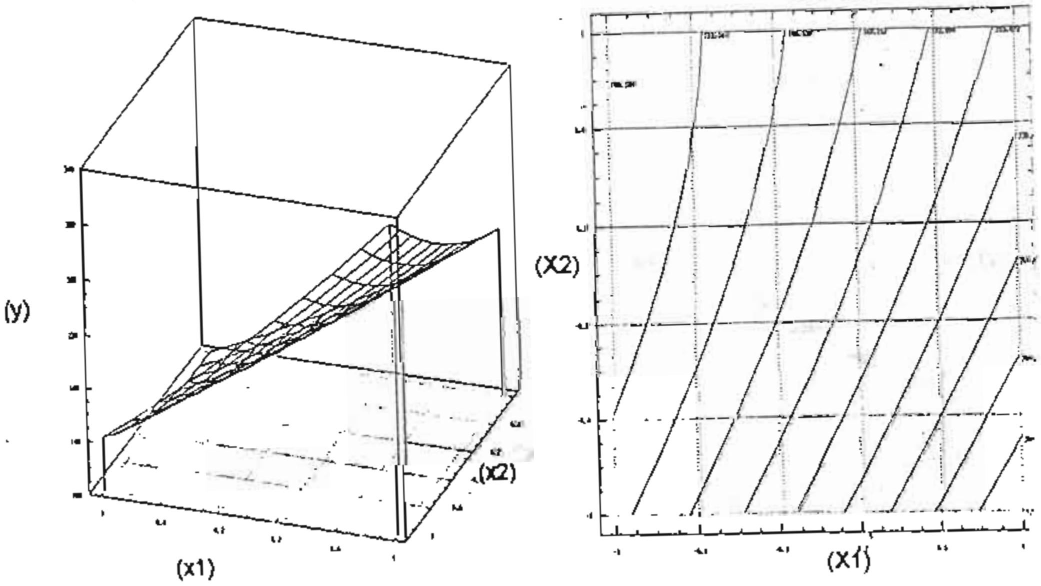
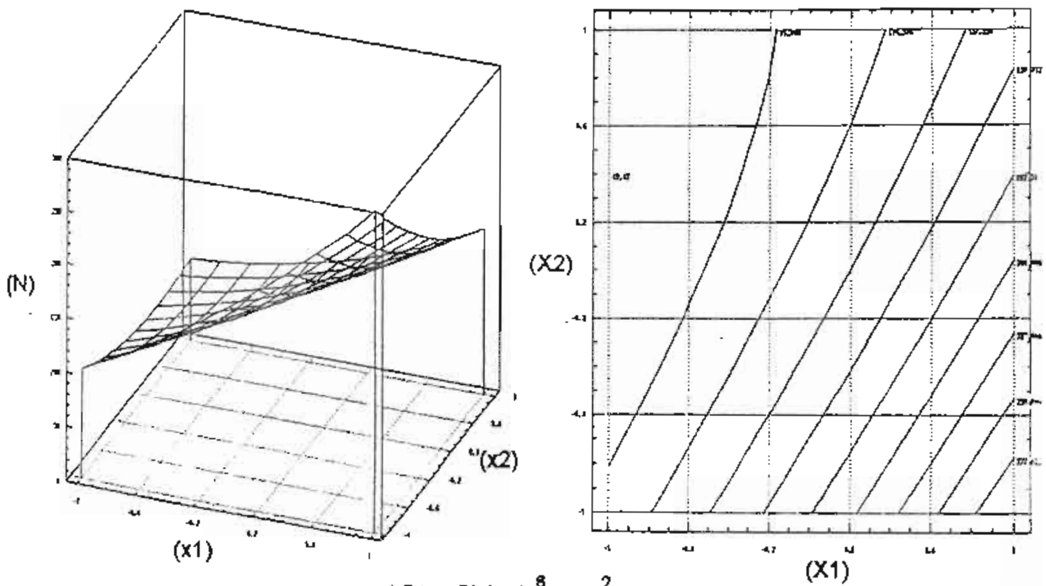


Fig 3(a-d) : Power consumption (N) versus diameter (X1) and length (X2) of torsion rod (for projectile velocity V = 40 m/sec)

(S ty = 25.4 x $10^6$ kp/$m^2$)

(a) surface

(b) contour



( S ty = 73.2 x $10^6$ kp/$m^2$)

(c) surface

(d) contour

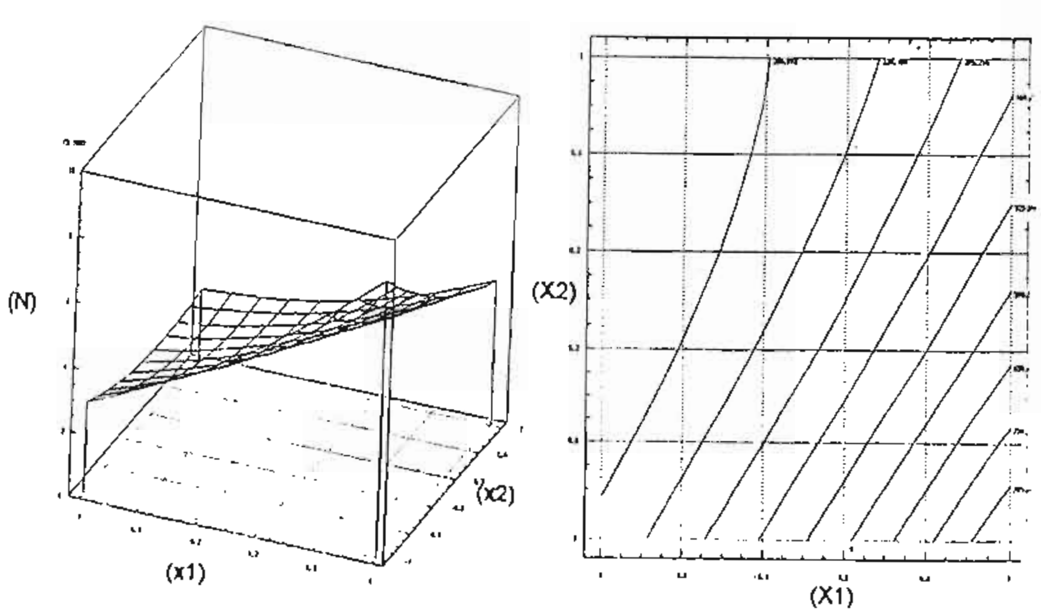
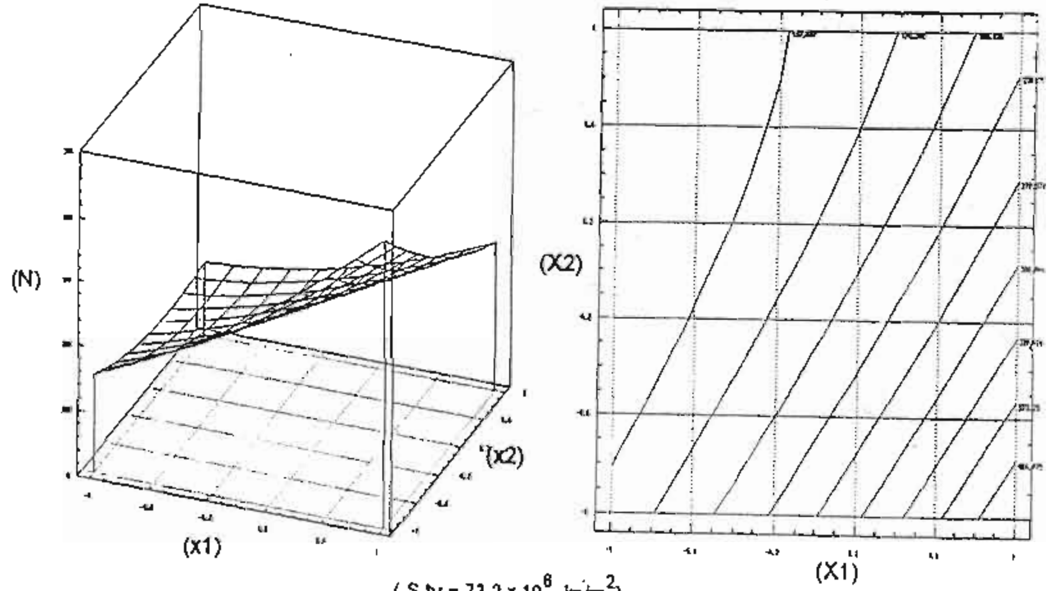


Fig 3(e-h) : Power consumption (N) versus diameter (X1) and length (X2) of torsion rod (for projectile velocity V = 60 m/sec)

(S ty = 25.4 x 10$^6$ kp/m$^2$)

(e) surface (f) contour



( S ty = 73.2 x 10$^6$ kp/m$^2$)

(g) surface (h) contour

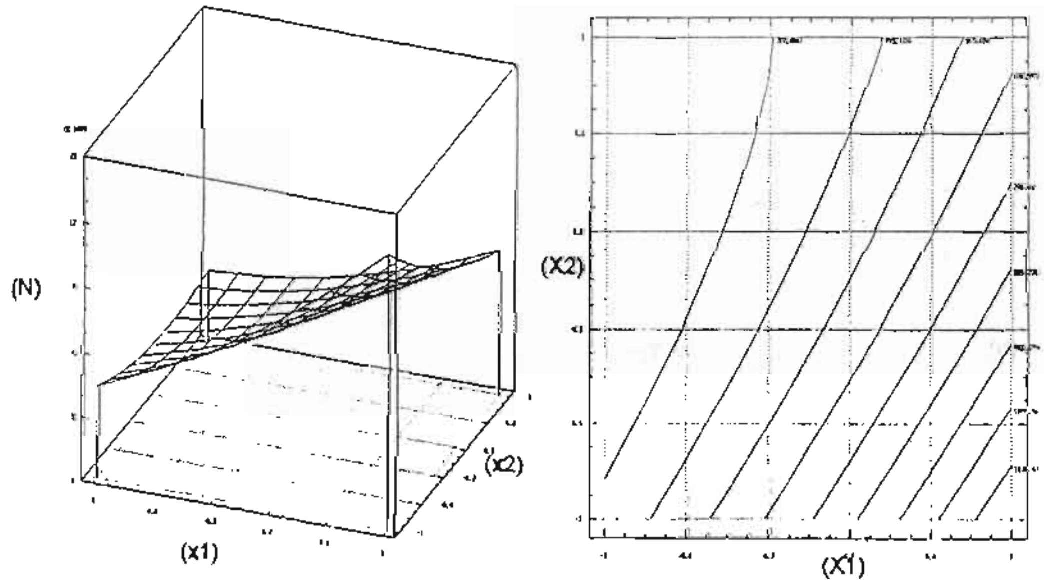
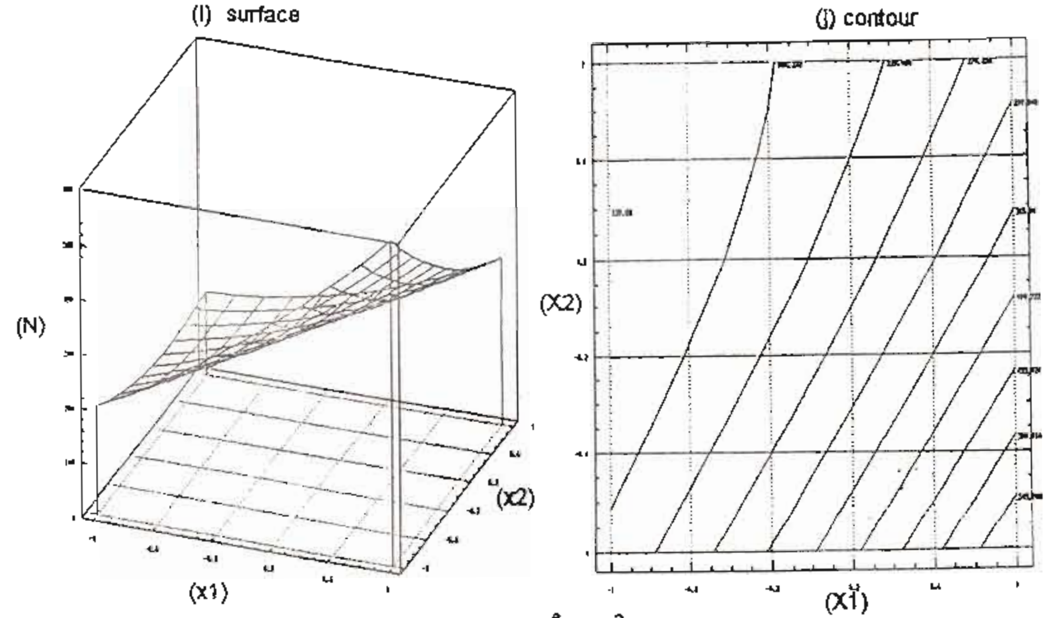


Fig 3(I-l) : Power consumption (N) versus diameter (X1) and length (X2) of torsion rod (for projectile velocity V = 80 m/sec)

(S ty = 25.4 x 10$^{6}$ kp/m$^{2}$)



( S ty = 73.2 x 10$^{6}$ kp/m$^{2}$)