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Parametric Approach to Analysis of Aluminum alloy Helical gear for High Speed Marine Applications

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ABSTRACT

In the present era of sophisticated technology, gear design has evolved to a high degree of perfection. The design and manufacture of precision cut gears, made from materials of high strength, have made it possible to produce gears which are capable of transmitting extremely large loads at extremely high circumferential speeds with very little noise, vibration and other undesirable aspects of gear drives. The gears are used for power transmission and also in marine and aerospace applications; where accuracy and power transmission capacity are the requirements. High speed gears (of the order of 30,000rpm) have to be of high quality to maintain contact and keep contact stresses within the limits. The analytical investigation is based on modified Lewis stress formula. The present work deals with the optimization of design and analysis of helical gear with aluminum alloy for high-speed marine applications.

Keywords - **Beam strength, bending stress, dynamic strength of tooth, Gear design, high speed helical gear.**

I. INTRODUCTION

The motion from one shaft to another shaft may be transmitted with belts, ropes and chains. These methods are mostly used when the two shafts are having long center distance. But if the distance between the two shafts is very small, then gears are used to transmit motion from one shaft to another. In case of belts and ropes, the drive is not positive. There is slip and creep that reduces velocity ratio. But gear drive is a positive and smooth drive, which transmit velocity ratio. Gears are used in many fields and under a wide range of conditions such as in smaller watches and instruments to the heaviest and most powerful machineries like lifting cranes. Gears are most commonly used for power transmission in all the modern devices. They have been used extensively in the high-speed marine engines. There is a great deal of researches on gear analysis. Generally their major concerns are on the analysis of gear stresses, transmission errors, dynamic loads, noise, and failure of gear tooth, which are very useful for optimal design of gear set. They have used various approaches and means to attain their main objectives. The first systematic studies in gear dynamics started in the 1920s by A.A.Ross and E.Buckingham . The basic concern in their studies was the prediction of tooth dynamic loads for designing gears to operate at high speeds. Helical gears are the modified form of spur gears, in which all the teeth are cut at a constant angle, known as helix angle, to the axis of the gear, where as in spur gear, teeth are cut parallel to the axis. The following are the requirements that must be met in the design of gear drive: the gear teeth should have sufficient strength, so that they will not fail under static and dynamic loading during normal running conditions. The gear teeth should have clear characteristics so that their life is satisfactory, the use of space and material should be economical. The alignment of the gears and deflections of the Shafts must be considered, because they affect the Performance of the gears. The lubrications of the gears must be satisfactory.

II. NOMENCLATURE

$[\sigma b]$ = Design Bending stress in N/mm²
E= Young's modulus in N/mm²
[Mt] = design torque in N-mm
σ_b = Bending stress N/mm²
β = Helix angle in degrees
Fd = Dynamic tooth load in N
Fb = Beam Strength of the gear tooth
FD = Design tooth load
m_n = Normal Module
Yv = Lewis Form factor
b =Face width in mm

DESIGN METHODOLOGY

Design of helical gear is based on "AGMA" Procedure:
Beam Strength of helical gear tooth, according to Lewis equation is given by

$$F_b = [\sigma_b] \cdot b \cdot \pi m_n \cdot y_v \, ,$$

Virtual number of teeth $Z_v = [Z/\cos^3 \beta]$

Design tooth load F_D,

$$F_D = F_t \times K_s \times C_v = \frac{F_t \times K_s \times C_v}{v}$$

Bending stress $\sigma_b = 0.7*(i+1)\,[M_T] / (a\, b\, m_n\, Y_V)$

Buckingham equation for dynamic load acting on gear

$$F_d = F_t + \frac{21v(Cb\cos^2\beta + F_t)\cos\beta}{21v + \sqrt{Cb\cos^2\beta + F_t}}$$

Wear Strength of tooth load $F_w = \frac{d_1 \cdot b \cdot Q \cdot K_w}{Cos^2\beta}$

III. RESULT AND DISCUSSIONS

It is aimed at arriving optimum values of bending stress, dynamic tooth load, beam strength to achieve low cost of manufacturing for Aluminum alloy by carrying out analysis under different operating parameters.

The effect of gear ratio, face width, helix angle, normal module on bending stress for Aluminum alloy

The variation of bending stress for different input variables are shown in figures.1(a) – (d). The fig 1(a) shows the relation between bending stress and gear ratio. The helix angle, face width, speed and normal module except gear ratio are kept constant. When the gear ratio is increased from 4 to 8, the corresponding bending stress remained constant. The fig 1(b) shows the relation between bending stress and face width. The helix angles, gear ratio, Speed, normal module except face width are kept constant. When face width is increased from 41 to 49, the corresponding bending stress is observed to decrease linearly from 562 kgf/cm^2 to 465 kgf/cm^2. The fig 1(c) shows the relation between bending stress and helix angle. The face width, gear ratio, speed and normal module except helix angle are kept constant. When helix angle is increased from 15^o to 35^o, the corresponding bending stress was observed to decrease from 560 kgf/cm^2 to 470 kgf/cm^2. The fig 1(d) shows the relation between bending stress and normal module. The face width, gear ratio, speed and helix angle except normal module are kept constant. When normal module is increased from 16mm to 24mm, the corresponding bending stress was observed to decrease from 560 kgf/cm^2 to 240 kgf/cm^2.

The effect of gear ratio, face width, helix angle, normal module on Dynamic tooth load for Aluminum alloy

The variation of Dynamic tooth load for different input variables are shown in figures. 2(a)-(d) .The fig 2(a) shows the relationship between Dynamic tooth load and gear ratio. The helix angle, face width, speed and normal module except gear ratio are kept constant. When gear ratio is increased from 4 to 8, the corresponding Dynamic tooth load remained constant. The fig 2(b) shows the relationship between Dynamic tooth load and Face width. The Helix angles, gear ratio, Speed, normal module except face width are kept constant. When face width is increased from 41 to 49, the corresponding Dynamic tooth load is constant. The fig 2(c) shows the relationship between Dynamic tooth load and Helix angle. The face width, gear ratio, speed and normal module except Helix angle are kept constant. When Helix angle is increased from 15^o to 35^o, the corresponding Dynamic tooth load decreased from 3340kgf to 2830kgf. The fig 2(d) shows the relationship between Dynamic tooth load and Normal module. The face width, gear ratio, speed and Helix angle except Normal module are kept constant. When Normal module is increased from 16mm to 24mm, the corresponding Dynamic tooth load decreased from 3350kgf to 2250kgf.

The effect of gear ratio, face width, helix angle, normal module on Beam Strength for Aluminum alloy

The variation of Beam Strength for different input variables are shown in figures. 3(a) – (d).The fig 3(a) shows the relationship between Beam Strength and gear ratio. The helix angle, face width, speed and normal module except gear ratio are kept constant. When gear ratio is increased from 4 to 8, the corresponding Beam Strength remained constant. The fig 3(b) shows the relationship between Beam Strength and Face width. The Helix angles, gear ratio, Speed, normal module except face width are kept constant. When face width is increased from 41 to 49, the corresponding Beam Strength increased from 3025kgf to 3625kgf. The fig 3(c) shows the relationship between Beam Strength and Helix angle. The face width, gear ratio, speed and normal module except Helix angle are kept constant. When Helix angle is increased from 15^o to 35^o, the corresponding Beam Strength remained constant. The fig 3(d) shows the relationship between Beam Strength and Normal module. The face width, gear ratio, speed and Helix angle except Normal module are kept constant. When Normal module is increased from 16mm to 24mm, the corresponding Beam Strength increased from 3030kgf to 4580kgf.

IV. DISCUSSIONS

In Parametric study of helical gear made of Aluminum alloy material, the variation of parameters viz bending stress, dynamic tooth load, beam strength for different modules (i.e 16, 18, 20, 22 & 24) and different face width (i.e 41,43,45,47 & 49) The gear ratio (i) = 4,5,6,7 & 8 and helix angle (β) = 15, 20, 25, 30 &35 are respectively kept constant. If the module is increased, the corresponding bending stress, dynamic tooth load was observed to decrease. However, beam strength were observed to gradually increase.

Optimum parameters for maximum bending stress: The effect of gear ratio, face width, helix angle, and normal module on optimum bending stress for aluminum alloy is carried out. If the helix angle, face width, speed and normal module except gear ratio are kept constant and the gear ratio is increased, the corresponding bending stress remained constant. Next the helix angle, gear ratio, speed, normal module except face width are kept constant and the face width is increased, the corresponding bending stress decreases linearly. The face width 41cm, corresponding to maximum bending stress is taken as constant value. The face width, gear ratio, speed and normal module except helix angle are kept constant and helix angle is increased, the corresponding bending stress was observed to decrease. The helix angle 15^0, corresponding to maximum bending

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stress is taken as constant. The face width, gear ratio, speed and helix angle except normal module are kept constant and normal module increases, the corresponding bending stress was observed to decrease. The normal module 16mm, corresponding to maximum bending stress is taken as constant.

Optimum parameters for maximum dynamic tooth load: The effect of gear ratio, face width, helix angle, and normal module on optimum dynamic tooth load is carried out. If the helix angle, face width, speed and normal module except gear ratio are kept constant and gear ratio is increased, the corresponding dynamic tooth load remained constant. When the helix angles, gear ratio, speed, normal module except face width are kept constant and face width is increased, the corresponding dynamic tooth load remained constant. When the face width, gear ratio, speed and normal module except helix angle are kept constant and helix angle is increased, the corresponding dynamic tooth load decreases. The helix angle 15^0, corresponding to maximum dynamic tooth load remains constant. The face width, gear ratio, speed and helix angle except normal module are kept constant and normal module is increased, the corresponding dynamic tooth load decreases. The normal module 16mm, corresponding to maximum dynamic tooth load is taken as constant.

Optimum parameters for maximum beam strength: The effect of gear ratio, face width, helix angle, normal module on optimum beam strength is carried out. If the helix angle, face width, speed and normal module except gear ratio are kept constant and gear ratio is increased, the corresponding beam strength remained constant. The helix angles, gear ratio, speed, normal module except face width are kept constant and face width is increased, the corresponding beam strength found to increase. The face width 49cm, corresponding to maximum beam strength is taken as constant. The face width, gear ratio, speed and normal module except helix angle are kept constant and helix angle is increased, the corresponding beam strength remained constant. The face width, gear ratio, speed and helix angle except normal module are kept constant and normal module is increased, the corresponding beam strength found to increase. The normal module 24mm, corresponding to maximum beam strength is taken as constant.

Manganese has been known to be an alloying element of Al alloys that contributes to uniform deformation. Recently, it was found that as the manganese content increases over 0.5% in such aluminum alloys, both yield and ultimate tensile strength increase significantly without decreasing ductility. The added manganese forms a manganese dispersoid, this dispersoid has an incoherent structural relationship with respect to the matrix, FCC, in retarding the motion of dislocations that increase strength. Once the dislocation is blocked by the dispersoid, it tends to change the slip system by means of cross-slip. This cross-slip allows the deformation to maintain uniformly good ductility. Adding manganese to aluminum alloys not only enhances tensile strength but also significantly improves low-cycle fatigue resistance. Corrosion resistance is also measurable improved by the addition of manganese. After extrusion, the recrystallization is also retarded so that a very small grain size is maintained, contributing to an improvement in the mechanical properties.

The addition of magnesium to aluminum increases strength through solid solution strengthening and improves their strain hardening ability. These alloys are the highest strength non-heat-treatable aluminum alloys and are, therefore, used extensively for structural applications. The alloys are produced mainly as sheet and plate and only occasionally as extrusions. The reason for this is that these alloys strain harden quickly and, are, therefore difficult and expensive to extrude.

V. CONCLUSIONS

Present day competitive business in global market has brought increasing awareness to optimize gear design. Current trends in engineering globalization require results to comply with various normalized standards to determine their common fundamentals and those approaches needed to identify "best practices" in industries. This can lead to various benefits including reduction in redundancies, cost containment related to adjustments between manufacturers for missing part interchangeability, and performance due to incompatibility of different standards. From the study of effect of various parameters (viz.bending stress, dynamic tooth load, beam strength) on the optimum design of helical gears for marine applications, the induced bending stresses are much lower than those of the results obtained theoretically. Also the bending stresses are much lower than the design stresses, thus the design is safe from the structural point of view. It is observed that the induced bending stresses are less than that of the theoretical calculations. Aluminum alloy reduces the weight up to 55-67% compared to other materials like steel. Weight reduction is a very important criterion, in order to minimize the unbalanced forces setup in the marine gear system, there by improves the system performance. The helical gear parameters that constitute the design are found to be safe from strength and rigidity point of view. Hence Aluminum alloy may be best possible material for marine gear in the high speed applications.

VI. ACKNOWLEDGMENTS

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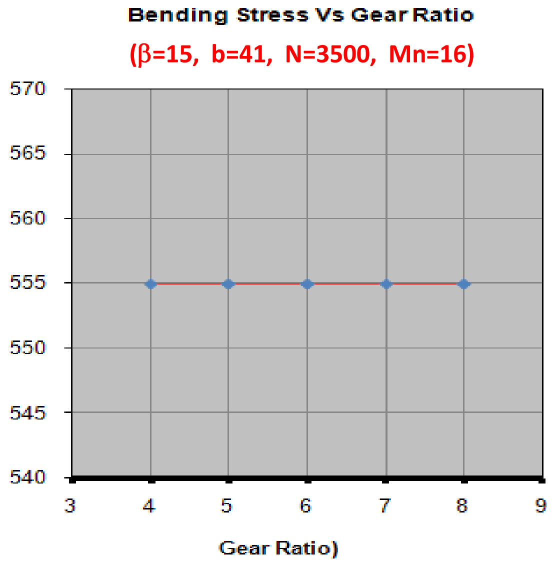
Variation of Bending Stress for different Input variables

1Unit = 1Kgf/Sq.cm



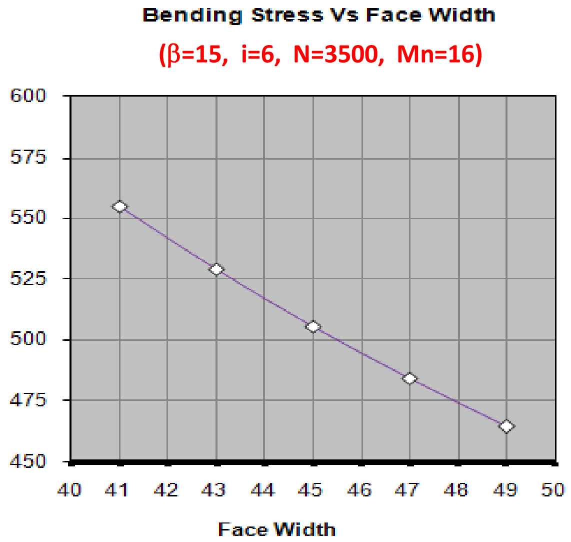
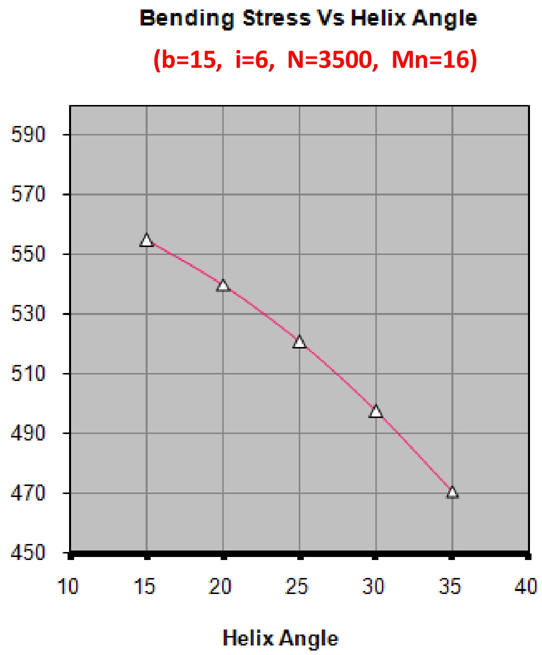


Fig.1(a)

Fig.1(b)



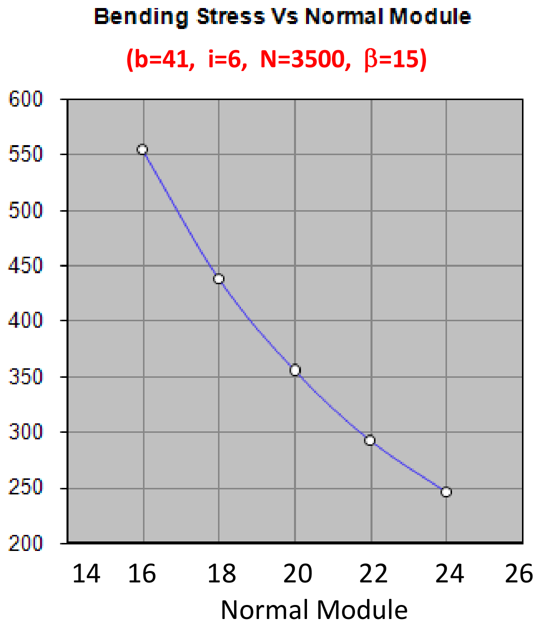


Fig.1(c)

Fig.1(d)

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Variation of Dynamic Tooth Load for different Input variables

1 Unit = 100 Kgf

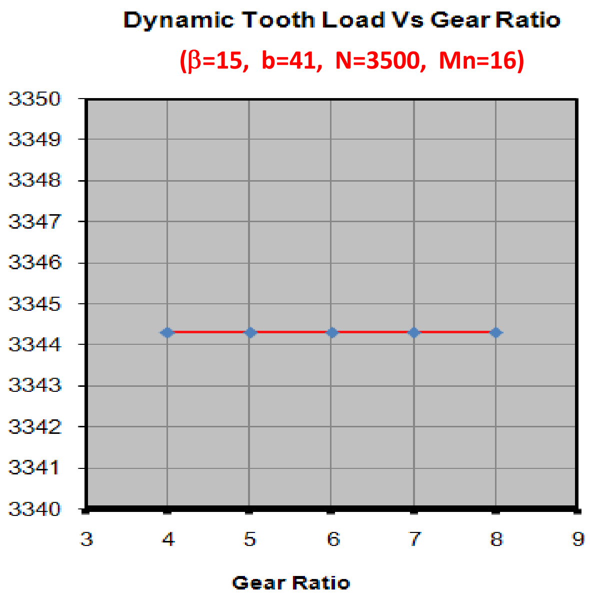
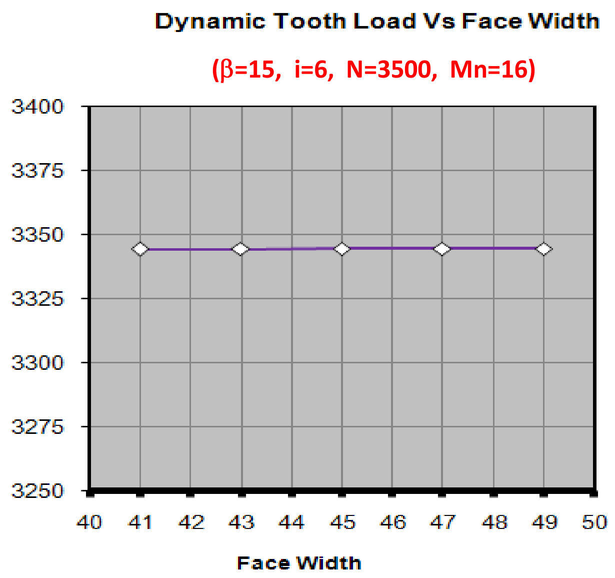


Fig.2(a)



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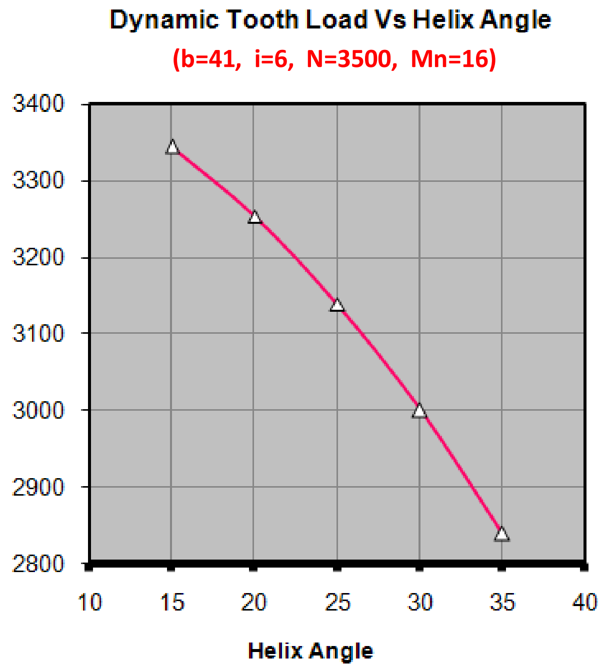

Fig.2(c)

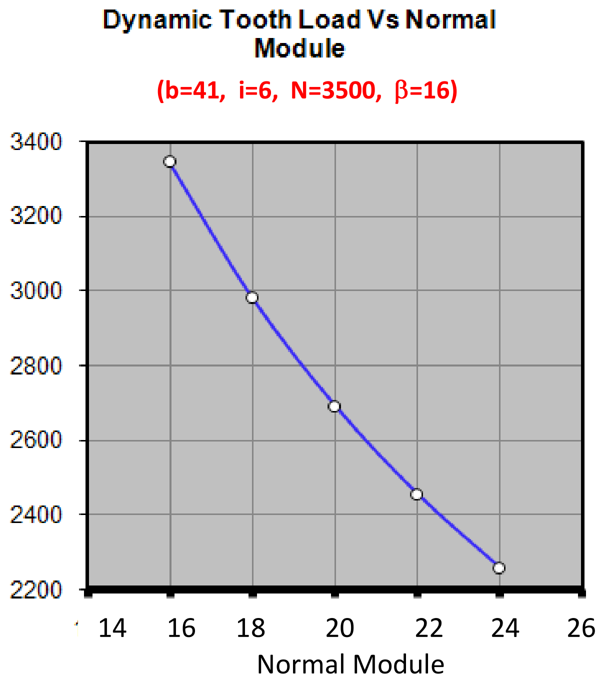

Fig.2(d)

Variation of Beam Strength for different Input variables

1 Unit = 100 Kgf

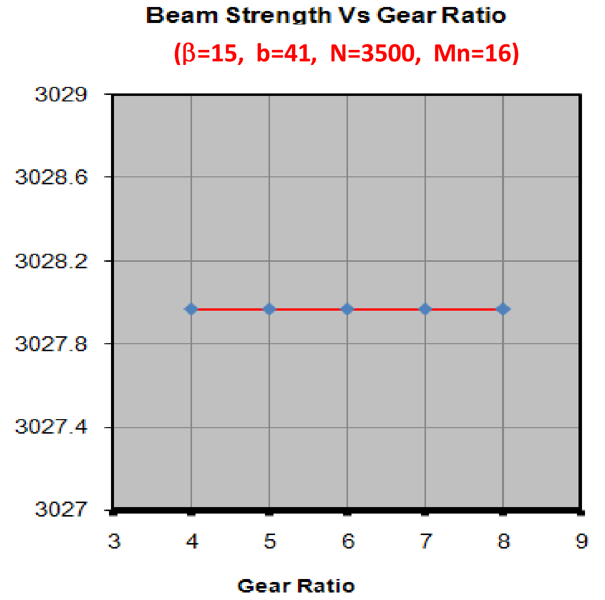

Fig.3(a)

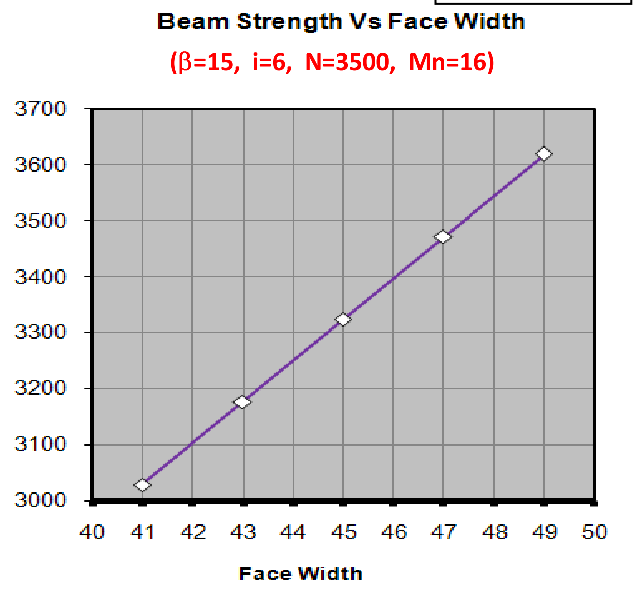

Fig.3(b)

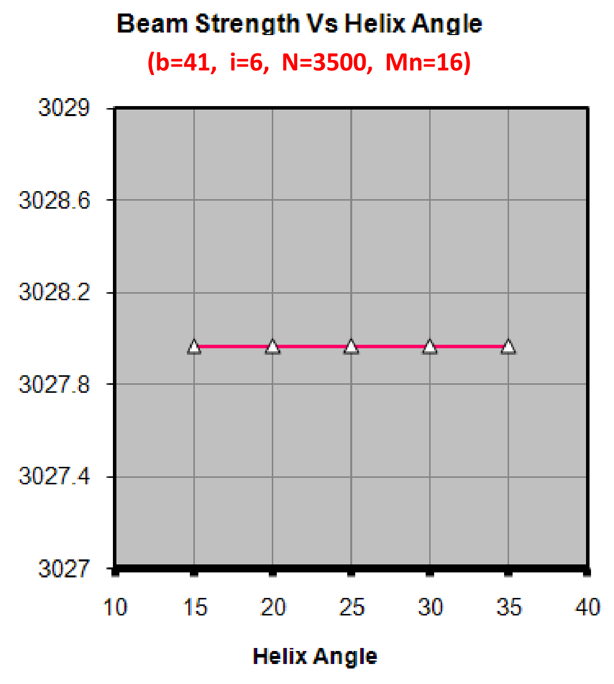

Fig.3(c)

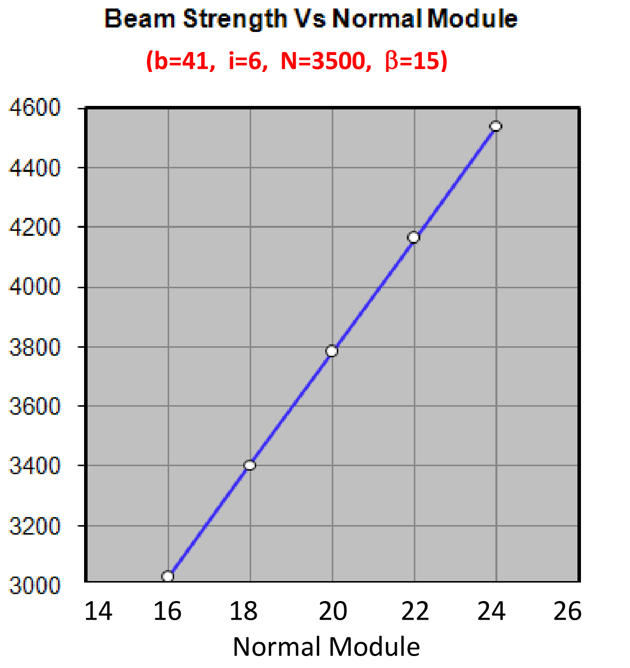

Fig.3(d)