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ANALYSIS AND OPTIMIZATION OF GEARBOX EFFICIENCY

Mr. Parth B. Shah[1], Mr. Chandresh Motka[2], Mr. Krunal A. Shah[3]

[1]*Department of Mechanical Engineering (MACHINE DESIGN), KIRC, Kalol*
[2]*Department of Mechanical Engineering (MACHINE DESIGN), KIRC, Kalol*
[3]*Department of Mechanical Engineering (CAD/CAM), HGCE, Ahmedabad*

Abstract — *The less efficiency of gear box of a machine tool is a serious problem as it increases maintenance cost and also affects the reputation of a firm. Hence its life has to be increased and should be made more reliable. The work to be done here is to find and rectify the causes of failure thereby improving the life of it. Also bearing failure should be reduced which is a cause of system failure. The alternative for the above problem is to design and optimization of a worm and worm gear box which reduced maintenance and improved reliability, lack of lubrication requirements, precise peak torque transmission, inherent overload protection, physically isolated input and output shafts, misalignment tolerance, and low acoustic noise and vibration etc. The parameters considered in the research are Lead Angle, Backlash and Bearing failure.*

Keywords- *Worm and Worm Gearbox, Double Disc Surface Grinding Machine, Efficiency, Backlash, Lead Angle, Bearing, Finite Element Analysis, Optimization.*

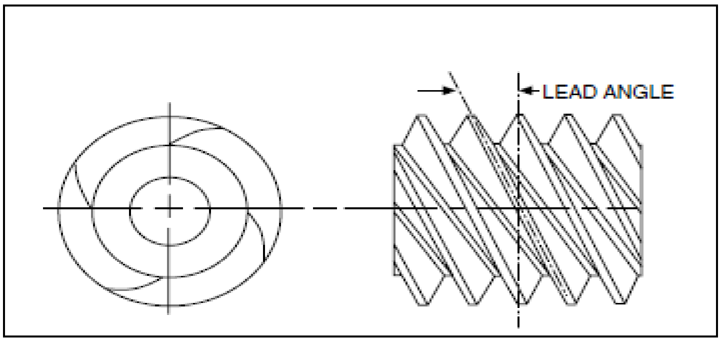
I. INTRODUCTION

In the double disc grinding machine, the work piece is fed through to the two grinding wheels which are, up to the required specification, fixed or movable. Various working modes include rotary, through-feed, reciprocating, and continuous and plunge grinding mode, which are selected according to process requirements.

In this type of surface grinding machine tools, Worm gear box is used to provide feed to the slide, to which grinding wheel is attached. Hence gear box is used to provide feed for surface grinding of work pieces. There had been problems like noise, Vibration, backlash, and with gradual time lapse, bearing failure and lubrication problem was also observed. But they didn't have any personnel to work for the same, and hence for their goodwill they decided to import readymade gear box and install it in their machine. By doing so, they had to change their earlier design and had to mount gear box externally, also the cost being high. Hence they wanted to sort the error as soon as possible.

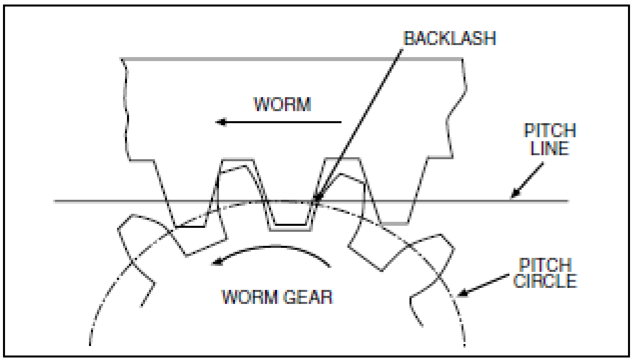
A. LEAD ANGLE

It is the angle between the tangent to the thread helix on the pitch cylinder and the plane normal to the axis of the worm. It is denoted by λ. A little consideration will show that if one complete turn of a worm thread be imagined to be unwound from the body of the worm, it will form an inclined plane whose base is equal to the pitch circumference of the worm and altitude equal to lead off the worm, as shown in Fig.



B. BACKLASH

Rotational movement of the output shaft when holding the input shaft stationary and rotating the output shaft alternately clockwise and counter clockwise. Backlash may be expressed in thousands of an inch measured at a specific radius at the output shaft.



C. *TYPE OF BEARING*

In Existing design of gearbox, Deep groove ball bearing is used in gearbox but unfortunately it was unable to take axial load acting during operation which causes bearing failure that leads to gearbox failure. So in New and Optimized design of gearbox, taper roller bearing and axial thrust bearing are used in gearbox instead of Deep groove ball bearing for improving efficiency.

II. LITERATURE REVIEW ON WORM AND WORM GEARBOX

[1] Study and Investigate Effect of Input Parameters on Temperature and Noise in Gearbox Using DOE, Rushil H. Sevak[1], Saurin Sheth[2] , IJEDR(2014) Volume 2, Issue 2 ISSN: 2321-9939.

In this research paper, Researcher suggest that before making gearbox, verification of its work, performance, efficiency, which effects gearbox performance is necessary. He used DOE techniques to achieve desired design of gearbox for control the temperature and noise levels in gearbox. He reached to the conclusion that it seems that the input speed, back lash, axial play of pinion and output shaft, oil viscosity are very crucial for the gearbox noise and temperature of oil. By optimizing input parameter, life of the gearbox will be increase [1].

[2] Optimization of gearbox efficiency, Bernd-Robert Höhn[1], Klaus Michaelis[2], Michael Hinterstoißer[3], Paper Ref: S0601_P0216 3rd International Conference on Integrity, Reliability and Failure, Porto/Portugal, 20-24 July 2009

Although mechanical gearboxes used as torque and speed converters have already very high efficiency it is not only a task in automotive applications to further decrease gearbox power losses but also in many industrial applications. Different methods are discussed for power loss reduction in a gearbox. No load losses can be reduced, especially at low temperatures and part load conditions when using low viscosity oils with a high viscosity index and low oil immersion depth of the components. This in turn influences the cooling properties in the gear and bearing meshes. Bearing systems can be optimized when using more efficient systems than cross loading arrangements with high preload. Low loss gears can contribute substantially to load dependent power loss reduction in the gear mesh. Low friction oils are available for further reduction of gear and bearing mesh losses. All in all a reduction of the gearbox losses in average of 50 % is technically feasible. The challenge is substantial power loss reduction with only minor impact on load carrying capacity, component size and weight and noise generation. Adequate compromises have to be proposed [2].

[3] Unbalance Response Prediction for Rotors on Ball bearings using Speed and Load dependent Nonlinear bearing stiffness, David P. Fleming[1], J. V. Poplawski[2], International Journal of Rotating Machinery 2005:1, 53–59 c_2005 Hindawi Publishing Corporation

Rolling-element bearing forces vary nonlinearly with bearing deflection. Thus, an accurate rotordynamic analysis requires that bearing forces corresponding to the actual bearing deflection be utilized. For this work, bearing forces were calculated by COBRAAHS, a recently developed rolling-element bearing analysis code. Bearing stiffness was found to be a strong function of bearing deflection, with higher deflection producing markedly higher stiffness. Curves fitted to the bearing data for a range of speeds and loads were supplied to a flexible rotor unbalance response analysis. The rotordynamic analysis showed that vibration response varied nonlinearly with the amount of rotor imbalance. Moreover, the increase in stiffness as critical speeds were approached caused a large increase in rotor and bearing vibration amplitude over part of the speed range compared to the case of constant stiffness bearings. Regions of bistable operation were possible, in which the amplitude at a given speed was much larger during rotor acceleration than during deceleration. A moderate amount of damping will eliminate the bistable region, but this damping is not inherent in ball bearings [3].

[4] A Model-Based Design Study Of Gearbox Induced Noise, Ulf Sellgren[1], Mats Åkerblom[2], International design conference - design 2004, Dubrovnik

In this research paper, Researcher takes a survey of the literature on gear noise and vibration. It is divided into three parts, "Transmission error", "Dynamic models" and "Noise and vibration measurement". The definition of transmission error is "The difference between the actual position of the output gear and the position it would occupy if the gear drive were perfectly conjugate". In addition to transmission error, friction and bending moment are other possible time varying noise excitation mechanisms that might be in the same order of magnitude as transmission error, at least in the case of low transmission error gears. Dynamic models of the system consisting of gears, shafts, bearings and gearbox casing are useful in order to understand and predict the dynamic behaviour of a gearbox. For relatively simple gear-systems it is possible to use lumped parameter dynamic models with springs, masses and viscous damping. For more complex models, which include for example the gearbox casing, finite element modelling is often used. Noise and vibration measurement and signal analysis are important tools when experimentally investigating gear noise because gears create noise at specific frequencies, related to number of teeth and the rotational speed of the gear [4].

[5] The study and analysis of a new Anti-backlash worm gear, Deng Xingqiao[1], Wang Jinge[2], Wang Qiang[3], Liu Qin-qin,Zhang Junfu[4], Paper Ref: S0601_P0216, 3rd International Conference on Integrity, Reliability and Failure, Porto/Portugal, 20-24 July 2009.

In this research paper, Researcher suggested a new kind of anti-backlash worm gearing has been proposed to eliminate the backlash in worm gearing and the structure work principle has been introduced. According to the theories of gear meshing, the author analyzes the contact line, the lubrication angle, and Induced normal curvature. The analyze results shows the proposed anti-backlash worm has three major advantages. First, the new kind worm can eliminate the backlash of worm gearing through the interleaving roller. Second, because the roller have changed the glide friction into the roll friction, the transmission efficiency and load capacity of the anti-backlash double-roller enveloping hourglass worm gearing is higher than that of an normal worm. Finally, because the new worm has large lubrication angle, it is difficult to occur the spalling, moreover, the roller can be changed easily when it corrupt [5].

III. ALGORITHM FOR OPTIMIZED VALUE OF GEARBOX EFFICIENCY

Step 1: Define
Input speed of the motor (N_1)
Input Power (P_1)
Circular Pitch (p_c)
Pitch Circle Diameter (D_p)
Lead for Existing Design (l_1)
Lead for Optimized Design (l_2)
Center Distance (x)
Number of Start (n)
Tangential Load (W_T)
Pressure Angle (φ)
Bearing type: 1 = Deep Groove Ball Bearing
2 = Thrust Bearing & Tapper Roller Bearing

Step 2: [Lead Angle: It is the angle between the tangent to the thread helix on the pitch cylinder and the plane normal to the axis of the worm.] Find λ

$\lambda = \tan^{-1} (l \div \pi D_p)$

Where l = Lead
D_p = Pitch Circle Diameter

Step 3: If λ == 9.09⁰ && Bearing type == Deep Groove Ball Bearing Then

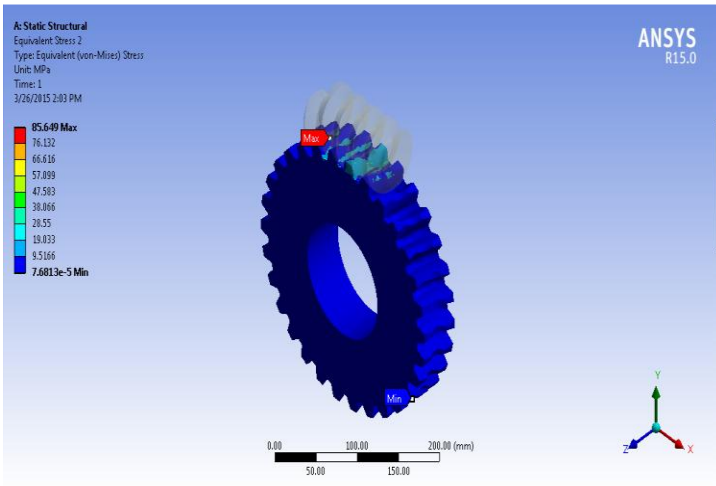
$v_r = \pi D_p N_1 \div \cos\lambda$
$\mu = 0.025 + (v_r \div 18000)$
$\eta = \tan\lambda (\cos\varphi - \mu\tan\lambda) \div (\cos\varphi \tan\lambda + \mu)$
$W_A = W_T \div \tan\lambda$
$W_R = W_A \tan\varphi$
$T_2 = T_1 \times \eta$
$Q_g = P_1 (1 - \eta)$

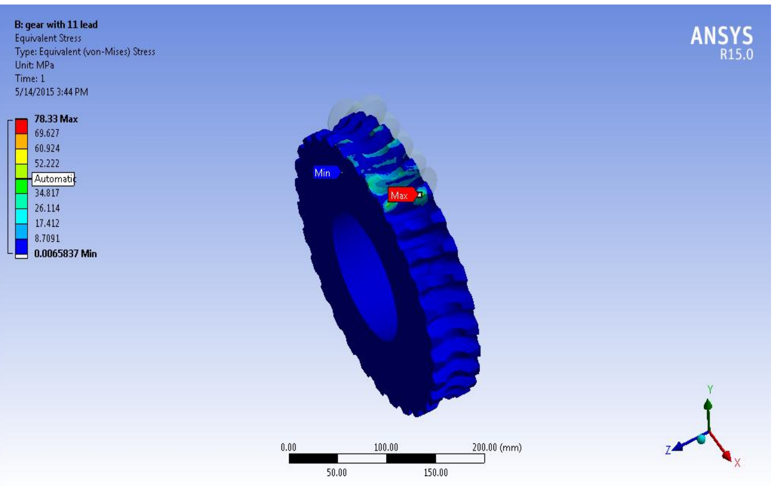
Where v_r = Rubbing Speed
μ = Coefficient of Friction
η = Efficiency

W_A = Axial Load
W_R = Radial Load
T_2 = Output Torque
Q_g = Power Loss in Friction
(Bearing can't take Axial & Radial Load that leads to bearing & gear tooth failure.)
Else if $\lambda == 11^0$ && Bearing type == Thrust bearing & Taper Roller Bearing
Then
$v_r = \pi D_p N_1 \div \cos\lambda$
$\mu = 0.025 + (v_r \div 18000)$
$\eta = \tan\lambda (\cos\varphi - \mu\tan\lambda) \div (\cos\varphi \tan\lambda + \mu)$
$W_A = W_T \div \tan\lambda$
$W_R = W_A \tan\varphi$
$T_2 = T_1 \times \eta$
$Q_g = P_1 (1 - \eta)$
(Efficiency Increases with improvement in lead angle.)
(Bearings can take axial as well as radial load so bearing failure reduces.)
(Output Torque increases and Power loss decreases with increasing lead angle.)
Else if $\lambda > 11^0$
(Efficiency may increase but there will be problem of Noise, Vibration & Gear tooth failure.)
End if

IV. ANALYSIS OF EXISTING AND OPTIMIZED DESIGN

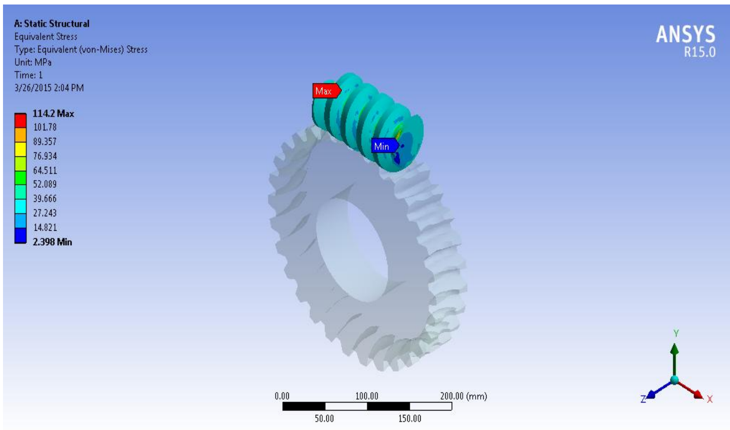
1. Total stress on worm wheel

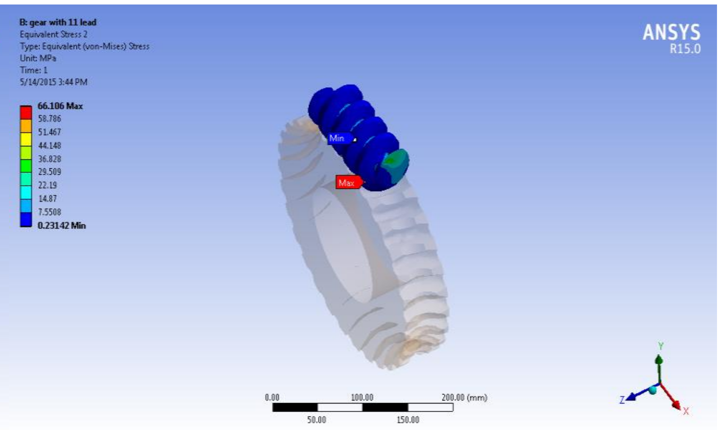




Existing Design Analysis **New Design Analysis**

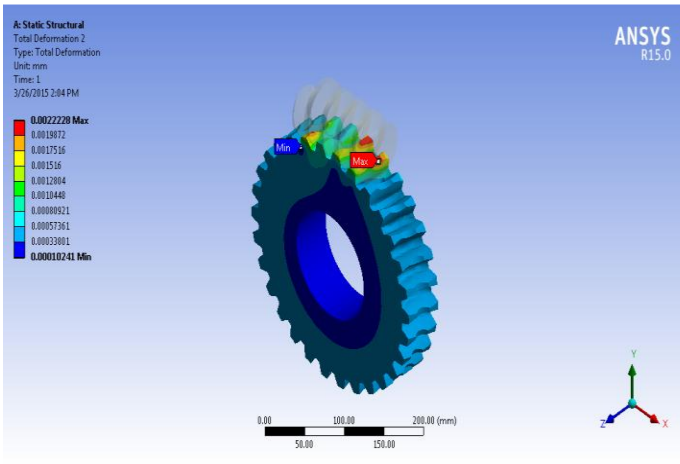
2. Total stress on worm



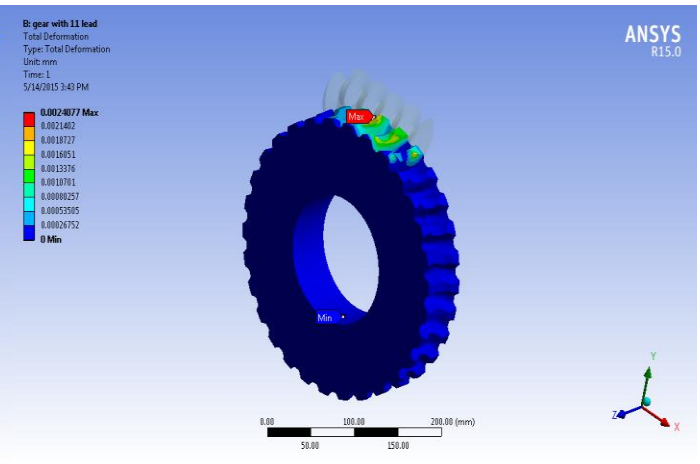


Existing Design Analysis **New Design Analysis**

3. Total Deformation of worm wheel

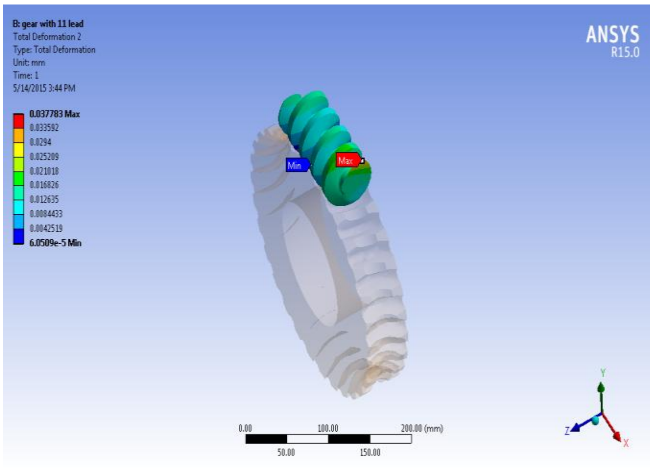


Existing Design Analysis

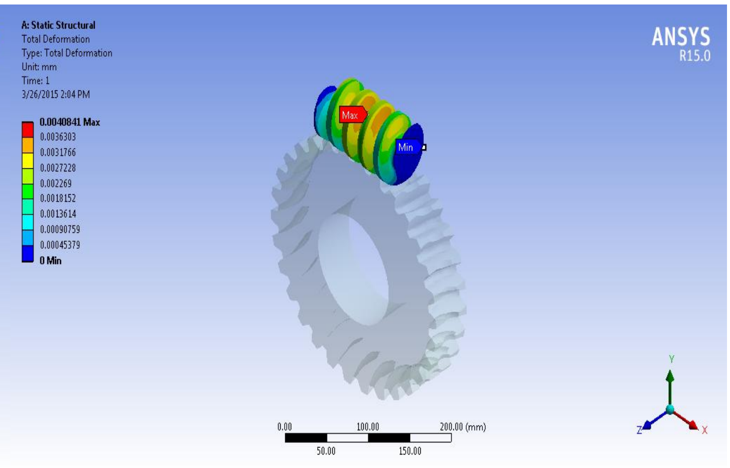


New Design Analysis

4. Total Deformation of worm

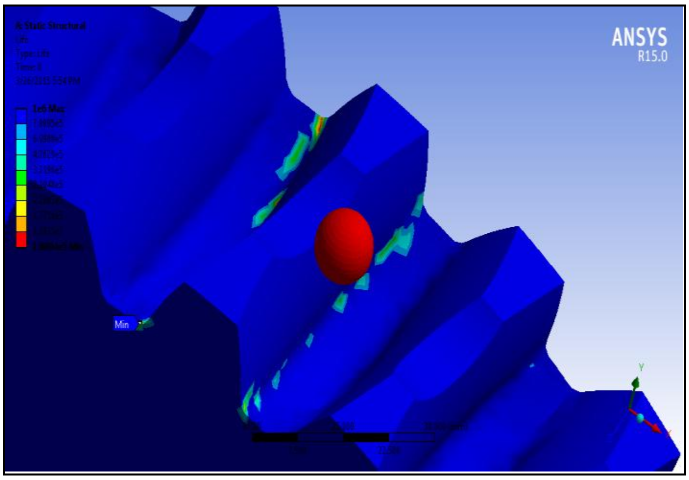


Existing Design Analysis

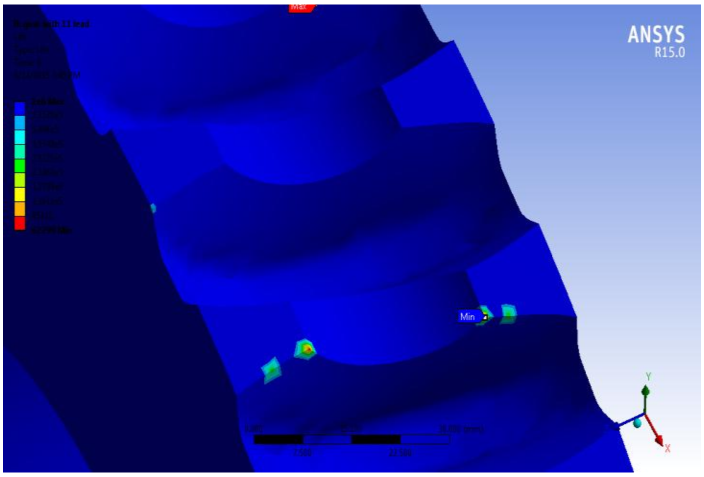


New Design Analysis

5. Fatigue Analysis



Existing Design Analysis



New Design Analysis

V. RESULTS

Parameters	Existing Component	Modified Component	Improvement
Lead Angle	**9.09^0**	**11.00^0**	**1.91^0**
Efficiency	**80.22 %**	**82.56%**	**2.34 %**
Output Power	**8.022 hp**	**8.256 hp**	**0.234 hp**
Output Torque	**39700.87 N mm**	**40858.94 N mm**	**1158.07 N mm**

Parameters	Existing Component	Modified Component	Reduction
Power Lost in Friction	**1475.58 watts**	**1301.02 watts**	**174.56 watts**
Tangential Force	**1947.65 N**	**1947.65 N**	**-**
Axial Force	**12180.42 N**	**10019.79 N**	**2160.63 N**
Radial Force	**3150.07 N**	**2591.29 N**	**558.78 N**

VI. CONCLUSION

As per the analysis of Worm and Worm gear, it is obvious that with the use of deep groove ball bearing, there is bearing failure and also due to high load, there will be gear tooth failure. So by optimizing the parameter lead angle and type of bearing with the use of algorithm which helps to improve the efficiency of gearbox and use of taper roller bearing and thrust bearing instead of deep groove ball bearing reduces the bearing failure and improves the life of bearing and gearbox.

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