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The Differential Planetary Gear Train Analysis of Mixer Reducer for Concrete Mixer Truck

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Abstract: *In general, the gears of mixer reducer for concrete mixer truck make use of the differential planetary gear train to rotate mixer drum smoothly on the initial operating conditions. The differential planetary gear train is composed to sun gear, differential pinion gear, ring gear, carrier and very important part of mixer reducer for concrete mixer truck because of strength problem. In the present study, calculate the gear specifications and analyze the gear bending stresses of the differential planetary gear system of mixer reducer. It is necessary to analyze gear bending stresses confidently for optimal design of the differential planetary gear train in respect of cost and reliability. In the paper, analyze actual gear bending stresses of the differential planetary gear train using Lewes equation and verify the calculated specifications of the differential planetary gear system by evaluating the results with the data of allowable bending stress from the suggested Stress – No. of cycles curves of gears.*

Keywords: *Concrete Mixer Truck, Mixer Reducer, Planetary Gear Train, Gear Bending Stress*

1. INTRODUCTION

Mixer reducer for concreter mixer truck is driven by a hydraulic motor, as an important device to rotate the mixer drum, and to convert to the required torque and rotational speed. Although the increasing initial torque resulting to the inertia moment increases of output section, the compound differential type planetary gear system applies the rotating motion that makes the mixer drum run smoothly which consists of the sun gear, the differential planetary gear and two ring gears. Gear teeth are damaged due to the lack of fatigue strength, compound planetary gears for mixer and by severe operating conditions of a concrete mixer truck that have become a problem.

TABLE 1: Specifications of the mixer reducer

Drum capacity	Hyd. Motor max. input torque/speed	Gear ratio	Max. output torque	Installation angle of drum
6~8 m^3	397 N·m /1,320rpm	132:1	52,400N·m	15~20°

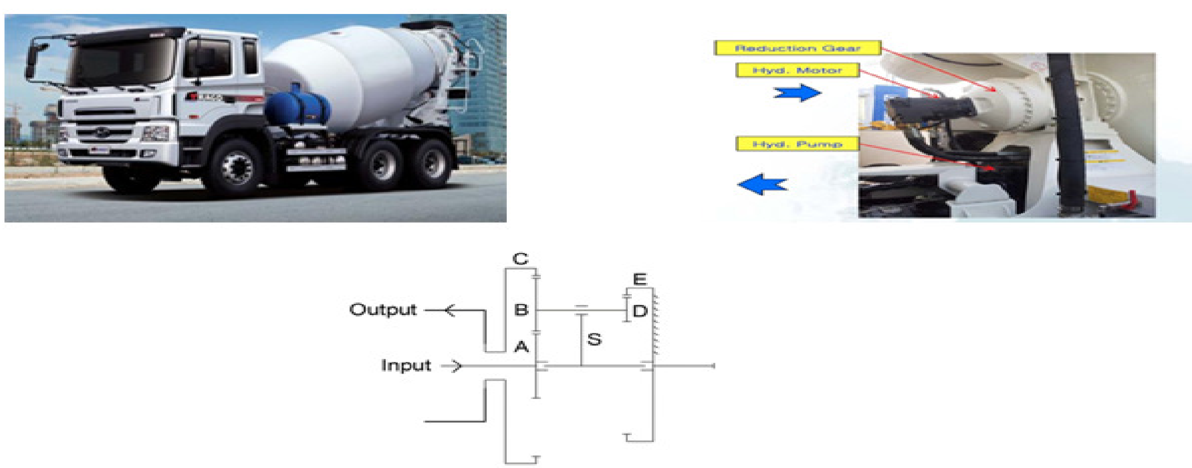

Fig. 1. Drum capacity, 6~8m³ class concrete mixer truck and driving-related parts of the mixer drum

The concrete mixer truck, is shown in Figure1, drum capacity, 6~8m^3 class concrete mixer truck. Figure 2 shows schematic diagram from analytical model of mixer reducer. Table 1 shows the specifications of the mixer reducer.

Several investigation have been reported, as cited by D.E. Imwalle[2] load equalization in planetary gear system. D.L. Seager[3] was established load distribution calculation of the planetary gear. F Cunliffe, J.D. Smith and D.B. Welbourn[4] Dynamic tooth loads in epicyclic gear for planetary gear. Castellani G., and V.P. Castelli[5] to the gear strength analysis method. Coy, J.J., D.P. Townsend, and E.V. Zaretsky[6] to the dynamic capacity and surface pressure durability life of spur and helical gear. Oda, satoshi and koji Tsubokura[7] to the effect of bending endurance strength for addendum modification of supr gear was likewise investigated. There is also an inclusion of typical bending atrength calculation of planetary gears AGMA 218.01[8] and gear Handbook by Duly, Darle W.[9] that shows bending strength calculation method of planetary gears.

Fig. 2. Schematic diagram of analytical model

Figure 3 shows the equation system solving with gear specifications calculation and stress analysis of the planetary gear system for mixer reducer.

In this study, developing planetary gear specifications calculation program and producing detailed specifications of the planetary gear system for mixer reducer based on gear Handbook by Dudly, Darle W. [9] Moreover, developing also the stress analysis program of planetary gear system by Lewes[1] equation and analyzing the safety factor of gear bending stresses considering required life time of mixer reducer and the S/N curve presented in the Gear Handbook by Dudly, Darle W.[9] It also verified the predictive validity with respect to the developed programs.

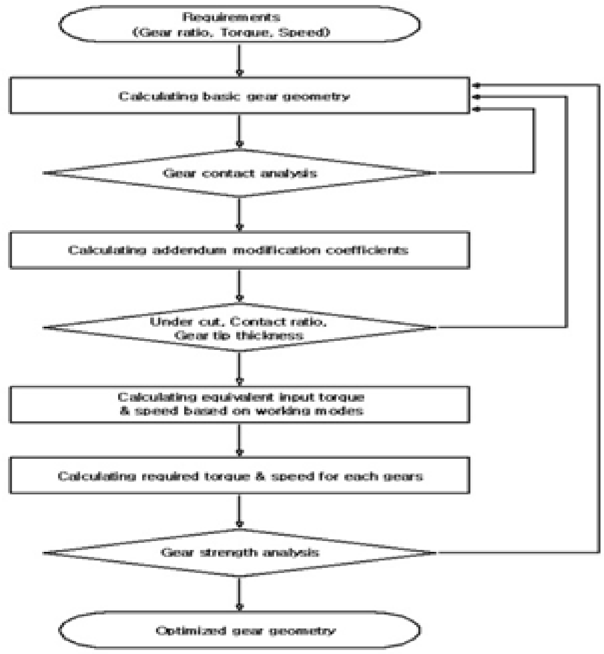

Fig. 3. Equation system solving with gear specifications calculation and strength analysis

2. MATERIAL AND ANALYTICAL METHOD

2.1 CALCULATION OF GEAR SPECIFICATIONS

Table 2 shows the gear specifications and Figure 4 shows the results of Lewes bending factors and tooth contact for the planetary gear system of mixer reducer by developed programs.

TABLE 2: Specifications of the planetary gear system

Item	Sun gear(A)	No.1 pinion gear(B)	No. 1 ring gear(C)	No. 2 pinion gear(D)	No. 2 ring gear(E)
Module	4	4	4	4	4
Pressure angle(°)	27	27	27	27	27
Helix angle(°)	0	0	0	0	0
No. gear teeth	10	35	80	31	76
Tooth modification factor	0	0	0	+0.5220	+0.5220
Pitch dia.	40	140	320	124	304
Outside dia.	48	148	312	136.176	300.176
Over pin measurement	$52.501^{-0.087}_{-0.163}$ ($\Phi 8$)	$151.338^{-0.104}_{-0.196}$ ($\Phi 7.5$)	$309.851^{+0.416}_{+0.257}$ ($\Phi 7$)	$140.320^{-0.094}_{-0.177}$ ($\Phi 8$)	$298.081^{+0.395}_{+0.244}$ ($\Phi 7$)
Face width	56	70	72.5	71	22
Backlash	0.117 ~ 0.220		0.184 ~ 0.314		0.184 ~ 0.314
Center distance	90		90		90

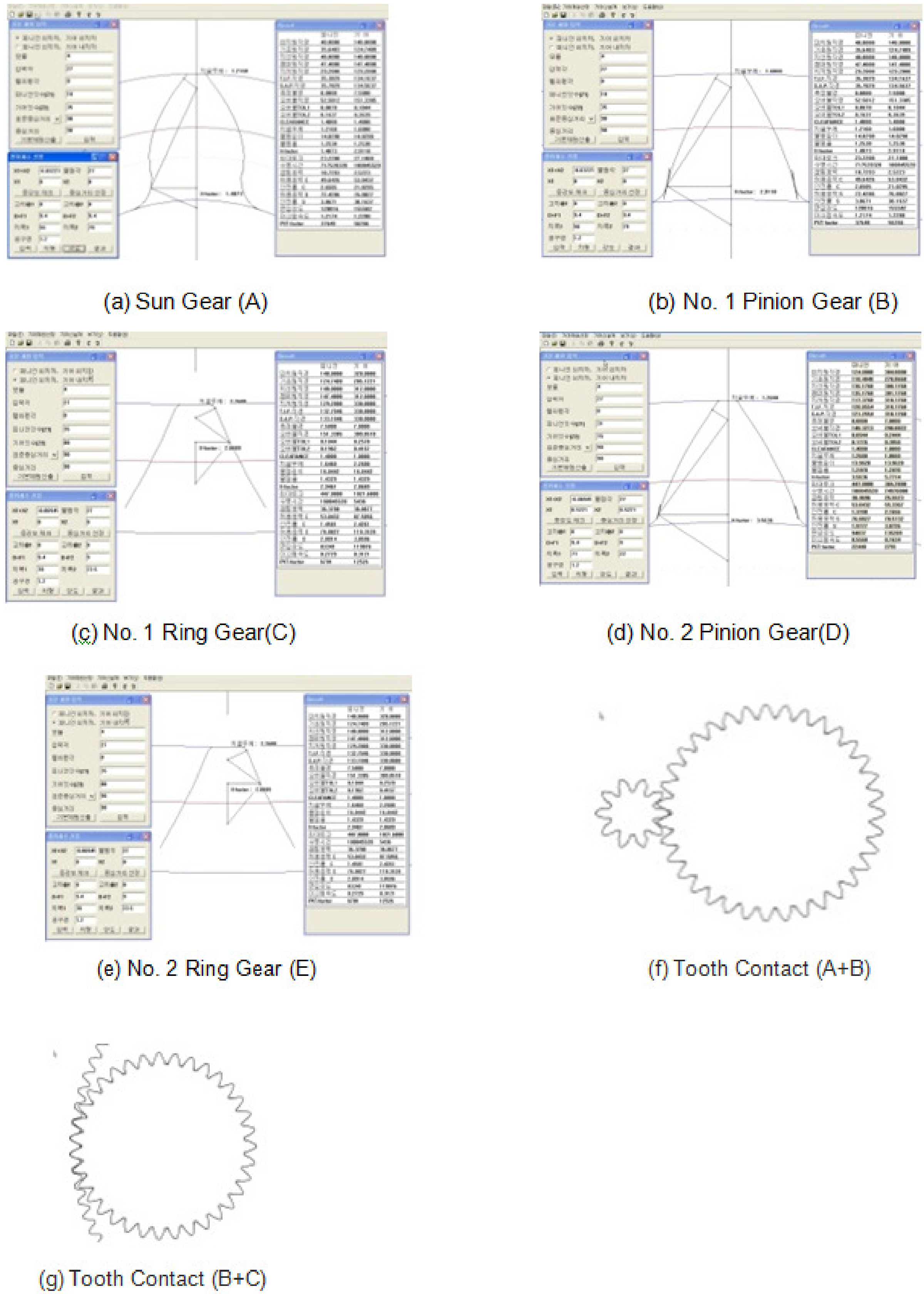

Fig. 4. Gear specifications and Lewes bending factors

2.2 INPUT EQUIVALENT TORQUE/ROTATION SPEED ANALYSIS

The required service period of life, for a concrete mixer truck is 15 years with the vehicle operation rate of 70%, operating time is set 12 hours for a day, based on the total 28,400 hours; as shown in Table 3.

TABLE 3: Operating mode and the required life period

Working mode	Frequency of use (%)	Working time(h)	Input		Duty cycle	Cycle ratio
			Torque(N·m)	Speed(rpm)		
Input concrete	4	1,136	189.9	1320	89971200	0.125391849
Driving	41	11,644	189.9	264	184440960	0.257053291
Normal working	12	3,408	241.7	660	134956800	0.188087774
Maximum working	1	284	284.8	132	2249280	0.003134796
Driving	38	10,792	52.4	264	170945280	0.238244514
Washing	4	1,136	52.4	1980	134956800	0.188087774
Total	100	28,400	-	-	717,520,320	1

Equivalent mean torgue for the average equivalent load of mixer reducer, T_{mi} is as follows:

$$T_{mi} = \left[\frac{\sum N_i t_i T_i^n}{\sum N_i t_i} \right]^{\frac{1}{n}} \tag{1}$$

where T_i is working torque, N is rotating speed, t is working time, n is power index (n = 20.8)

Equivalent mean rotating speed for the average equivalent rotating speed of mixer reducer, N_{mi} is as follows:

$$N_{mi} = \left[\frac{\sum N_i t_i}{\sum t_i} \right] \tag{2}$$

where N_{mi} is equivalent rotating speed for the average equivalent rotating speed, N_i is rotating speed, t_i is working time.

From the equation (1) and (2), the equivalent mean torque/rotating speed was calculated 227.6N·m /421.08 rpm.

2.3 TORQUE AND NUMBER OF ROTATION ANALYSIS

From schematic diagram Figure 2, gear ratio is as follows:

$$\Upsilon = \left\{ \frac{1 - Z_E Z_B / Z_D Z_C}{1 + Z_E Z_B / Z_D Z_A} \right\} \tag{3}$$

The number of rotation of each planetary gear calculated by relative speed diagram method is as follows:

$$N_B = N_D = \left\{ \frac{Z_A Z_C (N_A - N_C)}{Z_B (Z_A + Z_C)} \right\} \tag{4}$$

$$N_C = N_A / \Upsilon \tag{5}$$

$$N_S = \left\{ \frac{Z_A Z_D N_A}{(Z_E Z_B + Z_A Z_D)} \right\} \tag{6}$$

From the above equations, the torque and rotation speed is shown in Table 4.

TABLE 4: Torque and number of rotation (N·m/rpm)

T_A/N_A (Torque/Number of rotation of sun gear)	227.5 / 421.08
T_B/N_B (Torque/Number of rotation of NO.1 pinion gear)	4380.6(265.6) / 106.13
T_C/N_C (Torque/Number of rotation of NO.1 ring gear)	10,012.5 / 3.19
T_S/N_S (Torque/Number of rotation of carrier)	30,264.9 / 43.95
T_D/N_D (Torque/Number of rotation of NO.2 pinion gear)	4,380.6 / 106.13
T_E/N_E (Torque/Number of rotation of NO.2 ring gear)	3,579.7 / 43.95

where, Z_A is number of teeth of sun gear(10), Z_B is number of teeth of NO.1 pinion gear(35), Z_C is number of teeth of NO.1 ring gear(80), Z_S is the equivalent number of gear teeth of career, Z_D is number of teeth of NO.2 pinion gear(31), Z_E is number of teeth of NO. 2 ring gear (76)

2.4 GEAR BENDING STRESS ANALYSIS

Actual gear bending stress equation by Lewes[1] formula is as follows:

$$S = \frac{29{,}400\pi T}{N_a F X Z} \tag{7}$$

where, S is actual gear bending stress(N/mm^2), T is torque(N·m), N_a is length of action in the plane of rotation(mm), F is face width(mm), X is Lewes bending factor(mm), Z is number of teeth.

Allowable gear bending stress equation by Gear Handbook of Dudly, Darle W. [9] including gear bending S/N curve is as follows:

$$Sab = \frac{C_1}{N_F^{\frac{1}{20.8}}} \tag{8}$$

where, Sab is allowable gear bending stress(N/mm^2), N_F is No. of cycles, C_1 is coefficient

2.5 THE RESULTS OF GEAR BENDING STRESS ANALYSIS

Calculating actual gear bending stresses for planetary gear system of mixer reducer and considering allowable gear bending stresses, produce a safety factors and verify the problems of gear strength for the calculated specifications of the planetary gear system of mixer reducer.

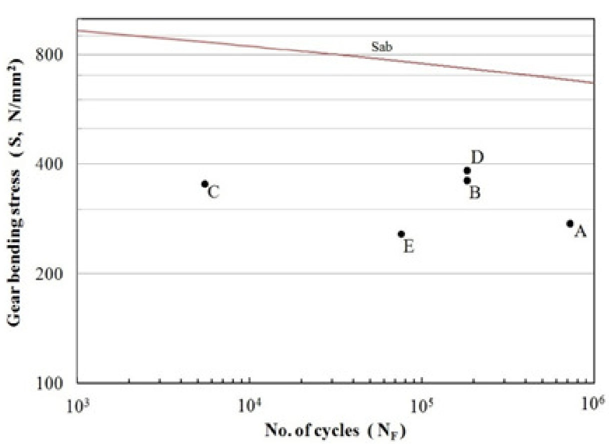

Fig. 5. The results of gear bending stress analysis

Figure 5 shows the results of gear bending stress analysis of planetary gear system for mixer reducer. Planetary gear system of mixer reducer for concrete mixer truck consisted of five gears. (A to E)

We can show that actual gear bending stresses of the planetary gear system are under the allowable gear bending stresses in these S/N curves. Thus calculation results are set safely and has been verified as valid.

3. CONCLUSIONS

In the study, we analyze actual gear bending stresses of the planetary gear system using lewes equation and verify the calculated specification of the planetary gear system by evaluating the results with the datea of allowable bending stress from the Stress-No Cycles curves of gears based on gear Handbook of dudly, Data w {9} for drum capacity, 6-8m3 Class Planetary gear system of mixer reducer for concrete mixer truck. Considering the result of gar bending stress analysis for the calculated specification of planetary gear system of mixer reducer for drum capacity,6-8m3 Class concrete mixer truck, the strength of planetary gear system and the developed programs have verified as valid. Reducer is an important component for construction machinery industry, the developed Programs Calculating the Specifications and analyzing the gear bending stresses of the differential planetary gear system of mixer reducer is expected to be effectively utilized. Future research on the more excellent the planetary gear system of the various reducers for construction machines is expected to be still performed.

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