Transamerica Delaval

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Date: MARCH 5. 1984

To: G. BESHOURI

c.c. G. E. RUSSELL

From: R. YANG

Subject: IACS - CIMAC RULES ON R-48 CRANKSHAFT

11" x 13" CRANKSHAFT, WITH 90000 PSI MATERIAL AND TORQUE RANGE OF +930000 TO -153000 FT. LB.

BASED ON	BENDING	TORSION	COMBINED	FACTOR OF SAFETY
CALCULATED STRESS CONC.	±30324 PSI	±18171 PSI	±45764 PSI	.6972 PSI
MEASURED STRESS CONC.	±32234 PSI	±13629 PSI	±34481 PSI	.9253 PSI

12" x 13" CRANKSHAFT, WITH 100,000 PSI MATERIAL AND TORQUE RANGE OF +212000 TO -106000 FT. LB.

BASED ON	BENDING	TORSION	COMBINED	FACTOR OF SAFETY
CALCULATED STRESS CONC.	±93041 PSI	±10335 PSI	± 31517 PSI	1.0422

Roland

Memo

C-39-1

Transamerica Delaval Engine Calculations

ENGINE ASSY. NO.

SHEET 1 OF 9

DATE MARCH 5. 1981

BY ROLAND YANG

PART NO.

CRANKSHAFT CALCULATION - BASED IACS DRAFT OF CIMAC PROPOSED RULES

THE IACS DRAFT OF CIMAC PROPOSED RULES WERE RECEIVED THROUGH THE COURTESY OF KOBE STEEL.

* RADIAL FORCES ON CRANKPIN WERE OBTAINED FROM BEARING LOAD ANALYSIS FOR 1650 PSI FIRING PRESSURE

11" x 13" CRANKSHAFT

COMPARATIVE ALTERNATING STRESS (TORSION WITH BENDING + MISALIGNMENT):-

90000 PSI MATERIAL
+230000 TO -153000 FT. LB. TORSUE RANGE

45764 PSI — BASED ON CALCULATED STRESS CONCENTRATION · FACTOR OF SAFETY = .6972

34481 PSI — " " MEASURED " " - " " " = .9253

12" x 13" CRANKSHAFT

COMPARATIVE ALTERNATING STRESS (TORSION WITH BENDING + MISALIGNMENT):-

100000 PSI MATERIAL
+212000 TO -106000 FT. LB. TORSUE RANGE

31517 PSI — BASED ON CALCULATED STRESS CONCENTRATION - FACTOR OF SAFETY = 1.0422

RULES FOR THE CALCULATION OF CRANKSHAFTS FOR DIESEL ENGINES - ICAS DRAFT.

ENGINE ___ ASS'Y. ___ NO. ___

SHEET 2 OF 9

2.1.2.

RADIAL FORCE P_B ACTING ON CRANKPIN DUE TO GAS AND INERTIA FORCES :

11"ϕ	@ 15°	275934 LB.	FROM BEARING LOAD ANALYSIS 1650 PSI FRING PRESSURE
	@ 360°	81670 LB.	
12"ϕ	@ 15°	277976 LB	" " " " " " " "
	@ 360°	79496 LB	

$$P_{BN} = \pm \tfrac{1}{2} (P_{B\,MAX} - P_{B\,MIN})$$

FOR 11" ϕ $P_{BN_1} = \pm \frac{1}{2} (275934 - 81670) = \pm 97132$ LB.

FOR 12" ϕ $P_{BN} = \pm \frac{1}{2} (277976 - 79496) = \pm 99240$ LB.

THE CYLINDER CENTER DISTANCE IS 24" = L_3 $L_2 = \frac{L_3}{2} = 12"$ $L_1 = 6.1875"$
THIS APPLIES TO BOTH THE 11" & 12" ϕ CRANKPIN SHAFTS.

$$M_{BN} = P_{BN} * L_1$$

11"ϕ $M_{BN} = \pm 97132 * 6.1875 = \pm 601004$ IN. LB.

12"ϕ $M_{BN} = \pm 99240 * 6.1875 = \pm 614047$ IN. LB.

W = WEB THICKNESS = 4.625"

B = WEB WIDTH = 21"

$W_{EG} = B * W^2/6 = 21 * 4.625^2/6 = 74.867$ IN³.

NOMINAL ALTERNATING BENDING STRESS γ_{BN} :-

$$\gamma_{BN} = \frac{\pm M_{BN}}{W_{EG}}.$$

11"ϕ $\gamma_{BN} = \frac{\pm 601004}{74.867} = \pm 8027$ PSI.

12"ϕ $\gamma_{BN} = \frac{\pm 614047}{74.867} = \pm 8202$ PSI.

NOMINAL ALTERNATING SHEAR FORCE Q_N :-

11"ϕ	@ 90°	37168 LB.	@ 15°	24517 LB.	FROM BEARING LOAD ANALYSIS 1650 PSI F.P
	@ 615°	-31986 LB.	@ 360°	0 LB.	
12"ϕ	@ 90°	34994 LB.	@ 15°	23955 LB.	
	@ 615°	-29887 LB.	@ 360°	0 LB.	
11"ϕ	Q_N	±34577 LB.		±12258 LB.	
12"ϕ	Q_N	±32440 LB.		±11977 LB.	

Form E-196-2

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ENGINE ASS'Y. NO.

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NOMINAL ALTERNATING SHEAR STRESS τ_{QN} :-

AREA REFERRED TO CROSS SECTION OF WEB $F = B \cdot W$

$= 21 \times 4.625$

$= 97.125 \text{ in}^2$.

11"ϕ $\tau_{QN} = \frac{\pm Q_N}{F} = \frac{\pm 34577}{97.125} = 356$ PSI. MAX. SHEAR STRESS

$\tau_{QN} = \frac{\pm 12258}{97.125} = 126$ PSI. CONCURRENT WITH τ_{BN} CALCULATED.

12"ϕ $\tau_{QN} = \frac{\pm 32440}{97.125} = 334$ PSI. MAX. SHEAR STRESS

$\tau_{QN} = \frac{\pm 11977}{97.125} = 123$ PSI. CONCURRENT WITH τ_{BN} CALCULATED

11"ϕ

2.1.3 ALTERNATING BENDING STRESS IN CRANKPIN FILLET

$\tau_{BH} = \pm \alpha_B \cdot \tau_{BN}$ $\alpha_B = \alpha_B = f = 3.464 \times 1.0906$

$= 3.7778 \times 8027$ $= 3.7778$.

$= \pm 30324$ PSI IF $\alpha_B = 2.77$ $\tau_{BH} = 22234$ PSI.

ALTERNATING BENDING STRESS IN JOURNAL FILLET

$\tau_{BG} = \pm (B_R \cdot \tau_{BN} + B_Q \cdot \tau_{QN})$

$= (2.9054 \times 1.0906) 8027 + (4.0512 \times 126)$ ← CONCURRENT WITH τ_{BN}

$= 25434 + 510 = 25944$ PSI.

2.2 CALCULATION OF ALTERNATING TORSIONAL STRESS:

$M_T = \frac{1}{2} (230000 - -153000) = \pm 191500$ FT. LB. $= \pm 2298000$ IN. LB.

CRANKPIN

$W_p = \frac{\pi D^3}{16} \cdot \frac{\pi 11^3}{16} = 261.3412$.

$\tau_N = \pm 2298000 / 261.3412 = \pm 8793$ PSI.

$\tau_H = \pm \alpha_T \cdot \tau_N = 2.0665 \times 8793 = \pm 18171$ PSI IF $\alpha_T = 1.55$ $\tau = 13629$ PSI.

JOURNAL

$W_p = \frac{\pi 13^3}{16} = 431.3799$.

$\tau_N = \pm 5327$ PSI.

$\tau_H = 1.875 \times 5327 = \pm 9988$ PSI.

11"

Form E-196-2

C-39-4

ENGINE | ASS'Y. | NO.

SHEET 4 OF 9

5. COMPARATIVE ALTERNATING STRESS

CRANKPIN FILLET

$$\sigma_V = \pm\sqrt{(\sigma_{BH} + \sigma_{ADD})^2 + 3 \times \tau_H^2}$$

$\sigma_{ADD} = 20\ N/mm^2 = 2900\ PSI$

$$= \pm\sqrt{(30324 + 2900)^2 + (3 \times 18171^2)}$$

$= 45764\ PSI.$ IF $\alpha = 2.77$ $\sigma_V = 34481\ PSI.$

JOURNAL FILLET

$$\sigma_V = \pm\sqrt{(\sigma_{BG} + \sigma_{ADD})^2 + 3 \times \tau_H^2}$$

$$= \pm\sqrt{(25944 + 2900)^2 + (3 \times 9988^2)}$$

$= 33634\ PSI.$

6. FATIGUE STRENGTH

$$\sigma_{DN} = \pm K(.42\sigma_B + 39.3)\left(.264 + 1.073 d^{-.2} + \frac{785 - \sigma_B}{4900} + \frac{196}{\sigma_B}\sqrt{\frac{1}{R_H}}\right)$$

$K = 1.0$

$\sigma_B = 90000\ PSI = 620\ N/mm^2$

$$\sigma_{DN} = \pm 1(.42 \times 620 + 39.3)\left(.264 + 1.073 \times 279.4^{-.2} + \frac{785 - 620}{4900} + \frac{196}{620}\sqrt{\frac{1}{12.7}}\right)$$

$$= \pm 299.10\,(.264 + .3478 + .033) + .0887)) = 220\ N/mm^2$$

$= 31906\ PSI$

8. FACTOR OF SAFETY (CRANKPIN)

$$S = \frac{31906}{45764} = .6972.$$ LESS THAN 1.15 Reqd. IF $\alpha_B = 2.77$, $\alpha_T = 1.55$, $S = .9753$

Form E-196-2

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12" ϕ

ENGINE ASS'Y. NO.

SHEET 5 OF 9

ALTERNATING BENDING STRESS IN CRANKPIN FILLET

$\gamma_{RH} = \pm \alpha_B \cdot \gamma_{RN}$

$= 2.8092 \cdot 8202$

$= 23041$ PSI

$\alpha_B = \alpha_R \times f = 2.4744 \times 1.1353$

$= 2.8092$

ALTERNATING TORSIONAL STRESS IN CRANKPIN FILLET.

$M_T = \frac{1}{2}(212\,000 - -106000) = \pm 159000$ FT. LB. $= \pm 1,908,000$ IN. LB.

$W_p = \frac{\pi D^3}{16} = \frac{\pi 12^3}{16} = 339.20$

$\tau_N = \pm 1908000 / 339.20 = \pm 5623$ PSI

$\tau_H = \pm \alpha_T \cdot \tau_N = 1.8381 \times 5623 = \pm 10335$ PSI

COMPARATIVE ALTERNATING STRESS IN CRANKPIN FILLET:

$\gamma_V = \pm \sqrt{(23041 + 2900)^2 + (3 \times 10335^2)}$

$= \pm 31517$ PSI

FATIGUE STRENGTH

$K = 1.0$

$\gamma_R = 100000$ PSI $= 689$ N/mm²

$\gamma_{DN} = \pm 1(.112 \times 689 + 39.3)\left(.264 + 1.073 \times 307.8^{-.2} + \frac{285 - 689}{4900} + \frac{196}{689}\sqrt{\frac{1}{19.5}}\right)$

$= \pm 328.68 (.264 + .3412 + .0196 + .0644) = 226.53$ N/mm²

$= 32846$ PSI

FACTOR OF SAFETY

$S = \frac{32846}{31517} = 1.0422$ LESS THAN 1.15 REQ'D.

Form E-196-2

C-39-6

3. Calculation of Stress Concentration Factors

ENGINE ____ ASS'Y. ____ NO. ____

SHEET A OF 9

D = Crankpin Diameter = 11" = 279.4 mm 12" = 304.8 mm

D_{BH} = Crankpin Bore Dia. = 0" = 0

R_H = Crankpin Fillet Rad = .5 = 12.7 .75" = 19.05

T_H = Recess of Crankpin = .4375" = 11.1125 .6875" = 17.4625

D_G = Journal Diameter = 13" = 330.2

D_{BG} = Journal Bore Dia = 0" = 0

R_G = Journal Fillet Rad. = .875" = 22.225

T_G = Recess of Journal = .008" = .2032

E = Pin Eccentricity = 10.5" = 266.7

S = Pin Overlap = 1.5 = 38.1 2" = 50.8

W = Web Thickness = 4.625" = 117.475

B = Web Width = 21" = 533.4

$T_{crankpin} = R_H/D = 12.7/279.4 = .0455$. $19.5/304.8 = .0640$.

$T_{Journal} = R_G/D = 22.225/279.4 = .0795$ $22.225/304.8 = .0729$.

$s = S/D = 38.1/279.4 = .1364$. $50.8/304.8 = .1667$.

$w = W/D = 117.475/279.4 = .4205$. $117.475/304.8 = .3854$.

$b = B/D = 533.4/279.4 = 1.9091$. $533.4/304.8 = 1.75$.

$d_G = D_{BG}/D = 0$ 0

$d_H = D_{BH}/D = 0$ 0

$t_H = T_H/D = 11.1125/279.4 = .0398$. $17.4625/304.8 = .0573$.

$t_G = T_G/D = .2032/279.4 = .0007$. $.2032/304.8 = .0007$.

Form E-196-2

C-39-7

11" ϕ

ENGINE ASS'Y. NO.

SHEET B OF 9

STRESS CONCENTRATION FACTOR FOR BENDING IN CRANKPIN FILLET.

$$\alpha_B = 2.6914 * f(S,W) * f(w) * f(b) * f(\tau) * f(d_G) * f(d_H)$$

$$f(S,W) = -4.1883 + (29.2004 \times .4205) - (77.5925 \times .4205^2) + (91.9454 \times .4205^3) - (40.0416 \times .4205^4) + (1 - .1364) \times (4.5400 - 58.3480 \times .4205 + 159.3415 \times .4205^2 - 192.5846 \times .4205^3 + 85.2916 \times .4205^4) + (1 - .1364)^2 \times (-3.8399 + 25.0444 \times .4205 - 70.5571 \times .4205^2 + 87.0328 \times .4205^3 - 39.1832 \times .4205^4)$$

$$= -4.1883 + 12.2788 - 13.7199 + 6.8364 - 1.2519 + .8636(9.5400 - 24.5353 + 28.1748 - 14.3192 + 2.667) + .7458(-3.8399 + 10.5312 - 12.4759 + 6.4211 - 1.2251)$$

$$= -.0449 + 1.3190 - .4017 = .8724.$$

$$f(w) = 2.1790 \times (.4205)^{.2121} = 1.1707$$

$$f(b) = .6840 - .0077 \times 1.9091 + .1473 \times 1.9091^2 = 1.2062.$$

$$f(\tau) = .2081 \times (.0455)^{-.5231} = 1.0478.$$

$$f(d_G) = .9993$$

$$f(d_H) = .9978$$

$$\alpha_B = 3.464.$$

STRESS CONCENTRATION FACTOR FOR BENDING IN JOURNAL FILLET.

$$\beta_B = 2.7146\ f_B(S,W) * f_B(w) * f_B(b) * f_B(\tau) * f_B(d_G) * f_B(d_H)$$

$$f_B(S,W) = -1.7625 + 2.9821 \times .4205 - 1.5276 \times .4205^2 + (1 - .1364)(5.1169 - 5.8089 \times .4205 + 3.1391 \times .4205^2) + (1 - .1364)^2(-2.1567 + 2.329) \times .4205 - 1.2952 \times .4205^3)$$

$$= -1.7625 + 1.2540 - .2701 + .8636(5.1169 - 2.4426 + .5551) + .7458(-2.1567 + .9796 - .2290)$$

$$= -.7786 + 2.7889 - 1.0487 = .9616.$$

$$f_B(w) = 2.2422 \times (.4205)^{.7548} = 1.1660$$

$$f_B(b) = .5616 + .119) \times 1.9091 + .1176 \times 1.9091^2 = 1.218).$$

$$f_B(\tau) = .1908 \times (.0795)^{-.3568} = .7814.$$

$$f_B(d_G) = 1.0012$$

$$f_B(d_H) = 1.0012$$

$$\beta_B = 2.9054.$$

Form E-196-2

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ENGINE ASS'Y. NO.

SHEET C OF 9

$\beta_Q = 3.0128\, f_Q(s) * f_Q(w) * f_Q(b) * f_Q(\tau) * f_Q(d_H)$

$f_Q(s) = .4368 + 2.1630 \times .8638 - 1.5212 \times .7458 = 1.1703$

$f_Q(w) = .4205/(.063) + .9369 \times .4205) = .9188$

$f_Q(b) = -5 + 1.9091 = 1.4091$

$f_Q(\tau) = .531 \times .0795^{-.2038} = .8931$

$f_Q(d_H) = .9937$

$\beta_Q = 4.0512$

Stress Concentration Factor for Torsion in Crankpin Fillet

$\alpha_T = .923 * f(\tau, s) * f(b)$

$f(\tau, s) = .0455^{(-.322 + .1015 \times .8636)} = 2.0629$

$f(b) = 7.8955 - 10.654 \times 1.9091 + 5.3482 \times 1.9091^2 - .85) \times 1.9091^3$

$= 7.8955 - 20.3396 + 19.4924 - .5963 = 1.0853$

$\alpha_T = 2.0665$

Stress Concentration Factor for Torsion in Journal Fillet

$\beta_T = .923 * f(\tau, s) * f(b)$ $\qquad \tau = \frac{R_G}{D_G} = \frac{22.225}{330.2} = .0673$

$f(\tau, s) = .0673^{(-.322 + .1015 \times .8836)} = 1.8718$

$f(b) = 1.0853$

$\beta_T = 1.875$

Stress Concentration Factor For Crankthrows with Relessed Fillets

Applicable to Bending

$f = 1 + (t_H + t_G) \cdot (1.8 + 3.2 \times s)$

$= 1 + (.0398 + .000)(1.8 + 3.2 \times .1364)$

$= 1.0906$

Form E-198-2

12" ϕ

ENGINE ASS'Y. NO.

SHEET 9 OF 9

Stress Concentration Factor For Bending in Crankpin Fillet

$$\alpha_B = 2.6914 \; f(S,w)\, f(w)\, f(b)\, f(r)\, f(d_G)\, f(d_H)$$

$$f(S,w) = -4.1883 + (29.2004 \times .3854) - (77.5925 \times .3854^2) + (91.9454 \times .3854^3)$$
$$-(40.0416 \times .3854^4) + (.8333)(9.5400 - 58.3480 \times .3854$$
$$+ 159.3415 \times .3854^2 - 192.5846 \times .3854^3 + 85.2916 \times .3854^4)$$
$$+(.6944)(-3.8399 + 25.0444 \times .3854 - 70.5571 \times .3854^2 + 87.0328 \times .3854^3 - 39.1832 \times .3854^4)$$

$$= -4.1883 + 11.2538 - 11.5251 + 5.2634 - .8834$$
$$+ .8333(9.5400 - 22.4873 + 23.6675 - 11.0244 + 1.8817)$$
$$+ .6944(-3.8399 + 9.6524 - 10.4801 + 4.9822 - .8645)$$
$$= -.0796 + 1.3145 - .3821 = .8528$$

$$f(w) = 2.1790\,(.3854)^{.5131} = 1.0998$$

$$f(b) = .6840 - .0077 \times 1.75 + .1473 \times 1.75^2 = 1.1216$$

$$f(r) = .2481 \times (.0640)^{-.5231} = .8765$$

$$f(d_G) = .9993$$

$$f(d_H) = .9978$$

$$\alpha_B = 2.4744$$

Stress Concentration Factor For Torsion in Crankpin Fillet.

$$\alpha_T = .923 \; f(r,s)\, f(b)$$

$$f(r,s) = .0640\,(-.322 + .1015 \times .8333) = 1.9206$$

$$f(b) = 7.8955 - 10.654 \times 1.75 + 5.3482 \times 1.75^2 - .857 \times 1.75^3 = 1.0369.$$

$$\alpha_T = 1.8381.$$

Stress Concentration Factor For Crankthrows with Recess Fillets

Applicable to Bending

$$f = 1 + (t_H + t_G)(1.8 + 3.2 \times S)$$
$$= 1 + (.0573 + .000)(1.8 + 3.2 \times .166)$$
$$= 1.1353.$$

Form E-136-2

C-39-10

ROLAND

PLS USE THE CIMAL RULES TO CALCULATE FALTOR OF SAFETY ON THE 11×13 & 12×13 SHAFTS, S THROW

USE 1600 PSI PEAK FIRING PRESS

ON 11×13 USE 90,000 PSI MAT'L AND ALT TORQUES OF ~~+230 FT-~~ +230,000 FT-LBF
- 153,000 FT-LBF

ON 12×13 USE ACTUAL MAT'L (109,000 PSI?) & 212,000 FT-LBF
-106,000 FT-LBF

ALSO ON 11×13 USE THEIR CALC STRESS CONCENTRATION.

THEN USE MEASURED $\alpha_{Bend} = 2.77$

$\alpha_{Torsion} = 1.55$