

Transaxle tolerance stack and fastener audit

Five-speed FWD manual transaxle, split aluminium case. Sample report generated by NativeCAD.

Assembly 175 parts, 30 fasteners and 2 plugs
Stacks 5 (preload x3, backlash, bolt clearance)
Generated 2026-10-21

1 Summary

Stack (mm)	Required	Worst case	RSS 3 sigma	MC out	Result
Output shaft bearing preload, as drawn	0.130..0.180	0.000..0.710	0.189..0.521	99.96%	FAIL
Output shaft bearing preload, machining tightened to +/-0.01 mm	0.130..0.180	-0.080..0.390	0.012..0.298	59.59%	FAIL
Output shaft bearing preload, spacer picked at assembly	0.130..0.180	0.133..0.177	0.139..0.171	0%	PASS
1st-gear backlash from the two castings	>= 0.075	0.086..0.160	0.107..0.139	0%	PASS
Case flange bolt clearance	>= 0.000	0.105..0.420	0.174..0.351	0%	PASS

Fastener audit	Fasteners	Seated	Findings	Advisories	Result
As designed	30	30	0	2	PASS
Copy with 4 planted mistakes	30	-	4	-	4 of 4 caught

FINDING Output shaft bearing preload as drawn: 0.000..0.710 mm worst case, required 0.130..0.180 mm.

The preload chain crosses the case flange: a bearing seat in the clutch housing, the flange, a bearing seat in the transaxle case, against two taper bearings and the shaft between them. 99.96% of 20,000 simulated builds miss the 0.130..0.180 mm window. Holding every machined span to +/-0.01 mm still fails at worst case (-0.080..0.390 mm): the two bought-in bearing widths alone spread 0.400 mm across a 0.050 mm window.

FIX Spacer picked at assembly: 0.133..0.177 mm worst case, 0% out.

Measure the gap under the rear bearing cup with crushed solder, then pick the spacer from the 0.03 mm range that gives 0.14 mm of preload. The two castings' seat spans, both bearing widths and the shaft span are all inside the measured gap, so they drop out of the stack.

2 Output shaft bearing preload, as drawn

Resultant axial preload of the output shaft's two taper roller bearings, mm (positive = squeeze)
Requirement 0.130..0.180 mm
Nominal 0.155 mm
Worst case 0.000..0.710 mm FAIL
RSS (3 sigma) 0.189..0.521 mm, mean 0.355 FAIL
Monte Carlo 20,000 builds: mean 0.355, range 0.122..0.599 mm, 19,992 out of spec (99.96%)

#	Contributor	Nominal	Tolerance	Gain	Var.	WC
1	front bearing 30207 width T 18.25	18.250	+0.200/0.000	1	36.3%	28.2%
2	rear bearing 30206 width T 17.25	17.250	+0.200/0.000	1	36.3%	28.2%
3	transaxle case: flange face to rear bearing seat, 188 +/-0.05	188.000	±0.050	-1	9.1%	14.1%
4	clutch housing: front bearing seat to flange face, 52 +/-0.05	52.000	±0.050	-1	9.1%	14.1%
5	output shaft: bearing shoulder span 203.555 +/-0.05	203.555	±0.050	1	9.1%	14.1%
6	preload spacer 1.1 +/-0.005	1.100	±0.005	1	0.1%	1.4%

| 1, 2: ISO 492 tolerance class Normal, metric taper roller bearing assembled width T: 0 / +200 um for d over 10 to 80 mm (SKF rolling bearings catalogue, tolerance table for tapered roller bearings, restating ISO 492)

| 3, 4: this design's drawing: bearing seats machined from the flange face in one setting,

+/-0.05 mm

| 5: this design's drawing: shoulder span ground +/-0.05 mm

| 6: ground spacer, +/-0.005 mm (this design's drawing)

3 Output shaft bearing preload, machining tightened to +/-0.01 mm

Resultant axial preload of the output shaft's two taper roller bearings, mm (positive = squeeze)
Requirement 0.130..0.180 mm
Nominal -0.045 mm
Worst case -0.080..0.390 mm FAIL
RSS (3 sigma) 0.012..0.298 mm, mean 0.155 FAIL
Monte Carlo 20,000 builds: mean 0.155, range -0.012..0.354 mm, 11,918 out of spec (59.59%)
Change Shaft shoulder span re-centred to 203.355 and every machined span held to +/-0.01 mm, still with one fixed spacer.

#	Contributor	Nominal	Tolerance	Gain	Var.	WC
1	front bearing 30207 width T 18.25	18.250	+0.200/0.000	1	49.2%	42.5%
2	rear bearing 30206 width T 17.25	17.250	+0.200/0.000	1	49.2%	42.5%
3	transaxle case: flange face to rear bearing seat, 188 +/-0.01	188.000	±0.010	-1	0.5%	4.3%
4	clutch housing: front bearing seat to flange face, 52 +/-0.01	52.000	±0.010	-1	0.5%	4.3%
5	output shaft: bearing shoulder span 203.355 +/-0.01	203.355	±0.010	1	0.5%	4.3%
6	preload spacer 1.1 +/-0.005	1.100	±0.005	1	0.1%	2.1%

| 1, 2: ISO 492 tolerance class Normal, metric taper roller bearing assembled width T: 0 / +200 um for d over 10 to 80 mm (SKF rolling bearings catalogue, tolerance table for tapered roller bearings, restating ISO 492)

| 3, 4, 5: the alternative: every machined span held to +/-0.01 mm

| 6: ground spacer, +/-0.005 mm (this design's drawing)

4 Output shaft bearing preload, spacer picked at assembly

Resultant axial preload of the output shaft's bearings after the spacer is selected, mm
Requirement 0.130..0.180 mm
Nominal 0.140 mm
Worst case 0.133..0.177 mm pass
RSS (3 sigma) 0.139..0.171 mm, mean 0.155 pass
Monte Carlo 20,000 builds: mean 0.155, range 0.135..0.176 mm, 0 out of spec (0%)
Change Measure the gap under the rear bearing cup with crushed solder, then pick the spacer from the 0.03 mm range that gives 0.14 mm of preload. The two castings' seat spans, both bearing widths and the shaft span are all inside the measured gap, so they drop out of the stack.

#	Contributor	Nominal	Tolerance	Gain	Var.	WC
1	spacer selected under the rear bearing cup: 0.03 mm step residual	0.000	+0.030/0.000	1	88.6%	68.2%
2	spacer selected under the rear bearing cup: gap gauging	0.000	±0.005	1	9.8%	22.7%
3	spacer selected under the rear bearing cup: selected shim's own thickness gauging	0.000	±0.002	-1	1.6%	9.1%
4	spacer selected under the rear bearing cup: target residual	0.140	0	1	0.0%	0.0%

5 1st-gear backlash from the two castings

Resultant normal backlash of the 15:50 1st-gear pair, mm
Requirement >= 0.075 mm
Nominal 0.111 mm
Worst case 0.086..0.160 mm pass

RSS (3 sigma) 0.107..0.139 mm, mean 0.123 pass

Monte Carlo 20,000 builds: mean 0.123, range 0.100..0.143 mm, 0 out of spec (0%)

#	Contributor	Nominal	Tolerance	Gain	Var.	WC
1	clutch housing bore centres 94 +/-0.025	0.000	±0.025	0.507	63.5%	34.2%
2	input front 6206 loose in its 62 H7 bore	0.000	+0.0215/0.000	0.507	11.7%	14.7%
3	output front 30207 runout Kia 20 um	0.000	±0.010	0.507	10.2%	13.7%
4	transaxle case bore centres 94 +/-0.025	0.000	±0.025	0.177	7.7%	11.9%
5	input front 6206 runout Kia 10 um	0.000	±0.005	0.507	2.5%	6.8%
6	input rear 6206 loose in its 62 H7 bore	0.000	+0.0215/0.000	0.177	1.4%	5.1%
7	input front 6206 internal clearance, half taken up	0.000	+0.010/+0.0025	0.507	1.4%	5.1%
8	output rear 30206 runout Kia 18 um	0.000	±0.009	0.177	1.0%	4.3%
9	input rear 6206 runout Kia 10 um	0.000	±0.005	0.177	0.3%	2.4%
10	input rear 6206 internal clearance, half taken up	0.000	+0.010/+0.0025	0.177	0.2%	1.8%
11	backlash cut into the teeth at a = 94	0.111	0	1	0.0%	0.0%

| 1, 4: this design's drawing: input-to-output bore centre distance 94 +/-0.025 mm in each casting (bores machined in one setting)

| 2, 6: ISO 286 H7 against the ISO 492 Normal outer diameter

| 3, 8: ISO 492 Normal, taper roller cone runout Kia: 18 um (d 18..30), 20 um (d 30..50)

| 5, 9: ISO 492 Normal inner-ring radial runout Kia, 10 um for d over 18 to 30 mm

| 7, 10: ISO 5753-1 group N radial internal clearance of deep-groove ball bearings, 5 .. 20 um for d over 24 to 30 mm; half is taken up in the direction that opens the centre distance

| 11: the gear pair as built analytic backlash)

6 Case flange bolt clearance

Resultant radial clearance between an M8 flange bolt and its 8.4 mm hole, mm

Requirement >= 0.000 mm

Nominal 0.200 mm

Worst case 0.105..0.420 mm pass

RSS (3 sigma) 0.174..0.351 mm, mean 0.263 pass

Monte Carlo 20,000 builds: mean 0.262, range 0.138..0.390 mm, 0 out of spec (0%)

#	Contributor	Nominal	Tolerance	Gain	Var.	WC
1	M8 6g major diameter (radius)	8.000	-0.028/-0.240	-0.5	35.9%	33.6%
2	case clearance holes, position dia 0.1	0.000	±0.050	-1	32.0%	31.8%
3	clutch housing tapped holes, position dia 0.1	0.000	±0.050	-1	32.0%	31.8%
4	dowel float in the case (10 H7/m6)	0.000	+0.0045/0.000	-1	0.1%	1.4%
5	dowel float in the clutch housing (10 H7/m6)	0.000	+0.0045/0.000	-1	0.1%	1.4%
6	clearance hole 8.4 at MMC (radius)	8.400	0	0.5	0.0%	0.0%

| 1: ISO 965-1 M8x1.25 class 6g: es = -28 um, major-diameter tolerance Td(6) = 212 um

| 2, 3: this design's drawing: flange bolt holes, position dia 0.1 to the dowel holes in both castings

| 4, 5: ISO 286 10 H7/m6

| 6: ISO 273 fine series clearance hole 8.4 for M8, toleranced H12 by that standard; entered at its smallest (MMC)

7 The joints and their fasteners

Joint	Hardware	Grade	M_A N.m	OEM	F_M kN	Clamp kN	Opening kN
case flange	16 x ISO 4162 - M8x30	10.9	43.42	44 +/- 5	26.62	266.24	37.29
end cover	8 x ISO 4162 - M6x20	8.8	12.43	-	9.9	49.47	0
bearing retainer	4 x ISO 4762 - M6x20	8.8	11.46	-	9.9	24.74	6.7

| Tightening torque M_A and preload F_M by VDI 2230 sheet 1 (simplified), mu_G = mu_K = 0.14.
Clamp = bolts x F_M / alpha_A. Opening = the gear thrusts that act on the joint at 250 N.m

input in 1st gear, summed at their worst sign. OEM: the F5M51-class service figure.

| drain plug: M18 x 1.5, 32 +/- 2 N.m on a new crush washer 18.3 x 26 x 1.5.

| fill and level plug: M18 x 1.5, 32 +/- 2 N.m on a new crush washer 18.3 x 26 x 1.5.

| Engaged / minimum thread (mm), drilled hole left under the tip (mm), measured hole (mm) and ISO 273 series, edge distance / wall (mm), preload F_M (kN), torque M_A (N.m).

Fastener	Size	Thread	Tip	Hole	Edge/wall	F_M	M_A	Result
Flange dowel 1	M10x20	press	0.5	reamed	14.99/9.99	-	-	advisory
Case flange bolt 1	M8x30	18/16	2	8.4 fin	14.99/10.79	26.62	43.42	pass
Case flange bolt 2	M8x30	18/16	2	8.4 fin	14.99/10.79	26.62	43.42	pass
Case flange bolt 3	M8x30	18/16	2	8.4 fin	14.99/10.79	26.62	43.42	pass
Case flange bolt 4	M8x30	18/16	2	8.4 fin	14.99/10.79	26.62	43.42	pass
Case flange bolt 5	M8x30	18/16	2	8.4 fin	14.99/10.79	26.62	43.42	pass
Case flange bolt 6	M8x30	18/16	2	8.4 fin	14.99/10.79	26.62	43.42	pass
Case flange bolt 7	M8x30	18/16	2	8.4 fin	14.99/10.79	26.62	43.42	pass
Case flange bolt 8	M8x30	18/16	2	8.4 fin	14.99/10.79	26.62	43.42	pass
Flange dowel 2	M10x20	press	0.5	reamed	14.99/9.99	-	-	advisory
Case flange bolt 9	M8x30	18/16	2	8.4 fin	14.99/10.79	26.62	43.42	pass
Case flange bolt 10	M8x30	18/16	2	8.4 fin	14.99/10.79	26.62	43.42	pass
Case flange bolt 11	M8x30	18/16	2	8.4 fin	14.99/10.79	26.62	43.42	pass
Case flange bolt 12	M8x30	18/16	2	8.4 fin	14.99/10.79	26.62	43.42	pass
Case flange bolt 13	M8x30	18/16	2	8.4 fin	14.99/10.79	26.62	43.42	pass
Case flange bolt 14	M8x30	18/16	2	8.4 fin	14.99/10.79	26.62	43.42	pass
Case flange bolt 15	M8x30	18/16	2	8.4 fin	14.98/10.78	26.62	43.42	pass
Case flange bolt 16	M8x30	18/16	2	8.4 fin	14.99/10.79	26.62	43.42	pass
End cover bolt 1	M6x20	14/12	2	6.26 fin	19.88/16.68	9.9	12.43	pass
End cover bolt 2	M6x20	14/12	2	6.26 fin	19.38/16.18	9.9	12.43	pass
End cover bolt 3	M6x20	14/12	2	6.26 fin	19.11/15.91	9.9	12.43	pass
End cover bolt 4	M6x20	14/12	2	6.26 fin	19.16/15.96	9.9	12.43	pass
End cover bolt 5	M6x20	14/12	2	6.26 fin	19.34/16.14	9.9	12.43	pass
End cover bolt 6	M6x20	14/12	2	6.26 fin	7.99/4.79	9.9	12.43	pass
End cover bolt 7	M6x20	14/12	2	6.26 fin	7.99/4.79	9.9	12.43	pass
End cover bolt 8	M6x20	14/12	2	6.26 fin	8.03/4.83	9.9	12.43	pass
Retainer screw 1	M6x20	15/12	2	6.46 med	8/4.7	9.9	11.46	pass
Retainer screw 2	M6x20	15/12	2	6.46 med	8/4.7	9.9	11.46	pass
Retainer screw 3	M6x20	15/12	2	6.46 med	8/4.7	9.9	11.46	pass
Retainer screw 4	M6x20	15/12	2	6.46 med	8/4.7	9.9	11.46	pass

Advisories

- | Flange dowel 1: a press fit in a blind hole with 0.5 mm of hole under it. Bottoming costs a dowel no clamp (it has none to lose) so this is not a finding, but a blind dowel hole still needs a vent or a relief groove or the pin rides on trapped air. Measured, reported, not judged.
- | Flange dowel 2: a press fit in a blind hole with 0.5 mm of hole under it. Bottoming costs a dowel no clamp (it has none to lose) so this is not a finding, but a blind dowel hole still needs a vent or a relief groove or the pin rides on trapped air. Measured, reported, not judged.

8 Fastener audit, copy with 4 planted mistakes

The same audit run on a copy of the assembly with 4 realistic mistakes planted in it. It reported exactly the 4 planted, none missing and none extra.

#	Planted	Fastener	Measured	Allowed	What the audit said
1	M8 x 30 replaced by M8 x 25: one length down out of 14 the same bin	Case flange bolt	13 mm	16 mm	13 mm of thread engaged; cast aluminium needs 16 mm (2 × d). Use the drawn length, or tap the hole deeper.

#	Planted	Fastener	Measured	Allowed	What the audit said
2	M6 x 20 replaced by M6 x 25: the cover is never clamped, whatever torque is applied	End cover bolt	4 -3 mm	0.5 mm	The bolt runs 3 mm past the bottom of the drilled hole, where at least 0.5 mm should be left under the tip. Use the drawn length, or drill the hole deeper.
3	a 30 x 14 x 4 harness bracket added 4 mm over this bolt head after the bolt pattern was fixed	Case flange bolt 3	3.5 mm	30 mm	3.5 mm of the 30 mm a socket needs is clear over the head. Move the bracket clear of the head, or fit it after the bolt is torqued.
4	an 8 mm oil drilling put 8 mm from this bolt's tapped hole, towards the input bearing bore	End cover bolt	6 4 mm	6 mm	4 mm from the tapped hole to the nearest surface, against a minimum of 6 mm: 0.8 mm of wall left where 3 mm is needed. Move the drilling away from the thread, or move the bolt.

9 Method and standards

Model	175 parts built as B-rep solids: castings, shafts, 6 helical pairs with solved mesh phase, bearings with their rolling elements, synchronisers, and every bolt, dowel and plug. Interference: 0 clashes over 620 part pairs.
Stacks	worst case, RSS (band = 3 sigma) and 20,000 Monte Carlo builds on the same chain; a selected spacer enters as its step residual, gap gauging and spacer gauging
Bearings	ISO 492 Normal widths and runout, ISO 5753-1 group N clearance; taper roller sizes ISO 355
Threads and holes	ISO 724 / ISO 965-1 6g, ISO 273 clearance-hole series, ISO 898-1 classes 8.8 and 10.9, ISO 4162 flange bolts
Joints	VDI 2230 sheet 1 simplified: preload and torque, head pressure (A9) on cast aluminium, residual clamp (R12/R13), thread strip (R11) from the casting's declared Rm 240 MPa (EN 1706 AlSi9Cu3)
Requirements	output shaft preload 0.13 to 0.18 mm, case bolts 44 +/- 5 N.m, plugs 32 +/- 2 N.m: F5M51-class factory service figures