



ENGINEERING TECHNICAL WHITE PAPER / DIMENSIONAL AND OPTICAL ALIGNMENT SYSTEMS

Dimensional Registration of MIL-DTL-38999 Series III Optical Connectors

How shell keying, insert true position and finite optical-contact float produce channel-to-channel insertion-loss variation

Document control	Designation
Document	XI-TP-38999-002 Revision B
Publisher	XiOptics LLC — Precision Optical Components
Scope	Series III cylindrical plug/receptacle shells, nominal 25-37 multichannel model, size-16 optical termini
Intended audience	Connector, optical-system, applications, manufacturing, metrology and qualification engineers
Technical basis	Historical 37-cavity tolerance analysis, newly organized engineering interpretation and newly drawn illustrations
Data classification	Modeled dimensional cases; not measured optical insertion-loss or current qualification results

Executive abstract

Optical insertion-loss variation in a densely populated MIL-DTL-38999 Series III connector can arise even when the individual termini pass ferrule geometry and optical inspection. The connecting mechanism is mechanical: the plug and receptacle cavity patterns do not necessarily occupy exactly coincident positions at the moment the termini engage. Shell-to-shell radial clearance, key/keyway rotational free play, keyway angular true position, insert clocking and the nominal cavity true-position tolerance accumulate to create a location-dependent approach offset. This offset is disproportionately large for cavities at the insert perimeter.

A historical 37-position worst-case study reported a mean cavity-to-cavity mismatch of 0.0254 in under a baseline shell configuration, falling to 0.0175 in when the mating halves both received improved keying/clocking controls and to 0.0208 in when only the plug was precision-controlled. A geometric idealization with no key/keyway rotational tolerance reported 0.0068 in. The figures are model outputs from dimensional tolerance assumptions, not measured insertion losses; no current product qualification or field performance follows automatically from these values.

The engineering design objective is not to eliminate the inherent compliance of the optical termini. It is to prevent unnecessary shell and insert errors from consuming the contacts’ limited radial and angular self-centering capability. Improved control of key positions, key/keyway clearance, shell engagement and installed insert alignment can contribute to more predictable multichannel optical performance while preserving the contact’s ability to float and maintain axial spring engagement.

1. Background, connector architecture and root-cause signature

A multichannel optical connector is a stack of distinct positioning systems. The circular metal shell locates relative to its mate via engaged diameters and keys; insulating inserts register cavity centerlines to the shell; removable size-16 termini occupy the cavities with retention and float clearances; alignment sleeves establish the local ferrule-to-ferrule axis; and the polished fiber cores establish the ultimate optical coupling interface.

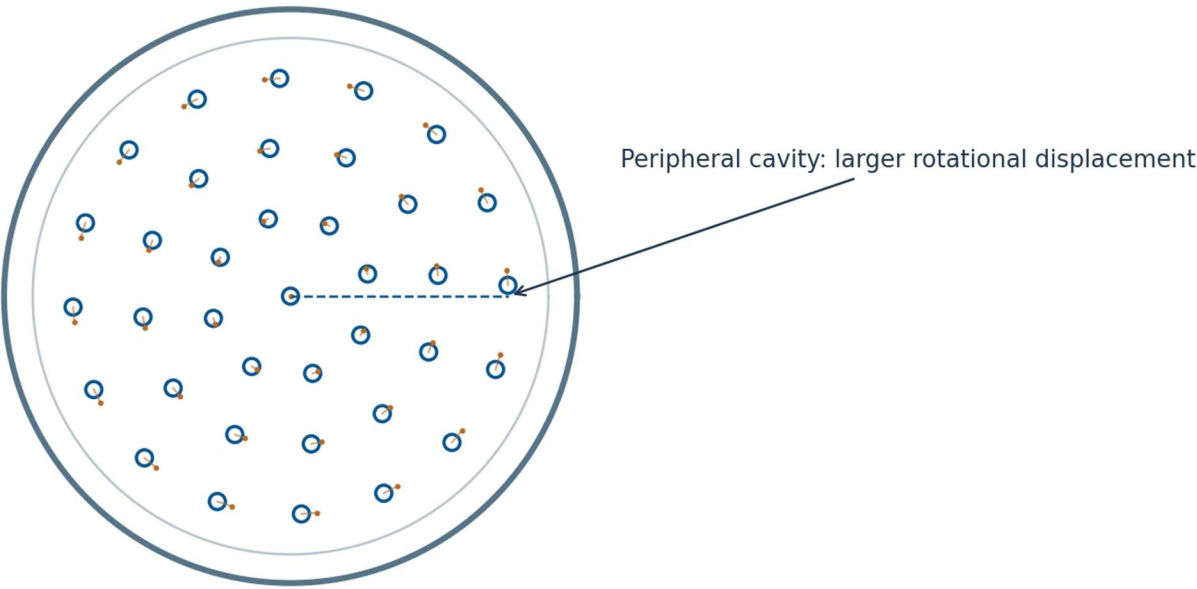
The observed failure signature motivating the original engineering investigation included higher than expected insertion loss, changes in loss near full engagement, changes in loss as coupling-nut preload was slightly altered, and disproportionate problems in the most radially distant cavities. These observations are mechanically consistent with a shell/cavity registration problem. They are not, by themselves, proof: endface condition, mating cleanliness, optical cable handling, termination eccentricity and measurement repeatability must also be evaluated.

2. A rigorous datum-chain description

For cavity i with nominal pattern coordinate $r_i = [x_i, y_i]^T$, define plug and receptacle frame translations t_p and t_r , their relative clocking θ_p and θ_r , and their local cavity-placement deviations $\varepsilon_{p,i}$ and $\varepsilon_{r,i}$. A simple rigid-body approximation is:

$$\Delta_i = (t_p - t_r) + [R(\theta_p) - R(\theta_r)]r_i + (\varepsilon_{p,i} - \varepsilon_{r,i})$$

The first term is transverse shell displacement. The second is relative rotation of the plug and receptacle cavity patterns. The third includes the differential error of insert installation and cavity manufacture. The vector magnitude $|\Delta_i|$ is the cavity-axis approach mismatch. It is not necessarily equal to the residual fiber-core displacement after the alignment sleeve has engaged.



Schematic 37-position example; not a dimensioned 25-37 insert drawing. Rotation exaggerated.

Figure 1. Newly drawn conceptual cavity-pattern schematic. A small relative angular error produces progressively larger displacement at larger cavity radius.

3. Rotational mismatch and the outer-channel penalty

If the shell axes are coaxial and the plug/receptacle pattern is rotated by $\Delta\theta$, the offset of a cavity at radius r due to rotation alone is $d = 2r \sin(|\Delta\theta|/2)$, approximately $r|\Delta\theta|$ with angle in radians. The sensitivity scales with radial distance and explains why an otherwise small clocking difference may become material to the outermost optical channels.

Cavity radius (in)	0.5° delta	1.0° delta	2.0° delta
0.100	0.87 mil	1.75 mil	3.49 mil
0.200	1.75 mil	3.49 mil	6.98 mil
0.300	2.62 mil	5.24 mil	10.47 mil
0.380	3.32 mil	6.63 mil	13.26 mil

This sensitivity table is a new first-principles calculation, not extracted from the historical study and not a statement of permissible dimensional limits. As an example, a 0.300-inch radial position with 1° of relative rotation produces roughly 5.24 mil of tangential cavity displacement before translational and true-position errors are considered.

4. Mechanical variables in the tolerance stack

4.1 Key/keyway clearance and angular true position

Mating key geometry governs insertion orientation, but finite width clearance and machining-location tolerances allow a range of shell clocking. Key width, keyway width, angular true position relative to the mating-axis datum, and the effective

engagement radius must all be considered. Reducing width alone does not eliminate angular displacement if the key angular location remains poorly controlled. Conversely, reducing the angular-position tolerance without adequate functional engagement control does not remove all free rotation.

4.2 Engaging diameters and relative transverse translation

The plug outside engagement diameter and mating receptacle inside diameter constrain shell axes while admitting manufacturing clearance and assembly movement. The worst-case tangential/angular cavity shifts can be reinforced or partially opposed by translational offset. Shell contact position, coupling torque and the force exerted by multiple spring-loaded optical channels can change the seated mechanical state.

4.3 Cavity true position, insert indexing and assembly fixturing

Cavities are controlled relative to the manufactured insert, but system alignment requires installed cavities to be referenced back to the shell keyway and shell axis. Controlled insert assembly fixtures and datum-based verification are therefore as important as individually inspecting the machined shell. The historical analysis explicitly modeled cavity true-position allowances and investigated fixture-based angular indexing.

4.4 Worst-case model interpretation

Worst-case geometry deliberately places adverse tolerance contributors in simultaneously unfavorable conditions. Such a stack identifies mechanical margin and design sensitivity; it does not predict manufacturing occurrence probabilities. Moreover, the historical study’s reported cavity “T.P.” values are consolidated position-mismatch metrics. Although the tabulated X/Y terms and contact-cavity allowances are preserved in the appendices, the archived paper does not present a fully traceable computation workbook. Consequently this revision retains the historical numeric results as reported rather than reverse-engineering or silently recalculating them.

5. Historical scenario definitions and comparative results

The analysis used a 37-cavity insert arrangement as a demanding multichannel example. The principal cases separated idealized key registration, baseline worst-case tolerance stacking and tighter control schemes. Table 2 presents the historical reported summary values; the full reported cavity records are retained in Appendices A–D.

Case	Configuration / scenario intent	Reported mean T.P. (in)	Comparative interpretation
S1	Idealized zero angular key/keyway tolerance; common shell center	0.0068	Reference lower-bound geometry; not a manufactured tolerance claim
S2	Baseline worst case, original key/keyway and cavity T.P. assumptions	0.0254	High cavity mismatch and significant peripheral exposure
S3	Precision-control of plug and receptacle keying	0.0175	Improved registration throughout the cavity pattern
S4	Precision-control applied to plug only	0.0208	Partial gain; mating-half constraints remain

The S3 average is approximately 31% lower than S2 when the two printed summary averages are compared directly; S4 is approximately 18% lower on the same basis. The source tables separately contain percentage-improvement columns calculated from their original unrounded model and sometimes different baselines. Those printed percentages are not identical to ratios of the rounded summary averages and must not be substituted for them.

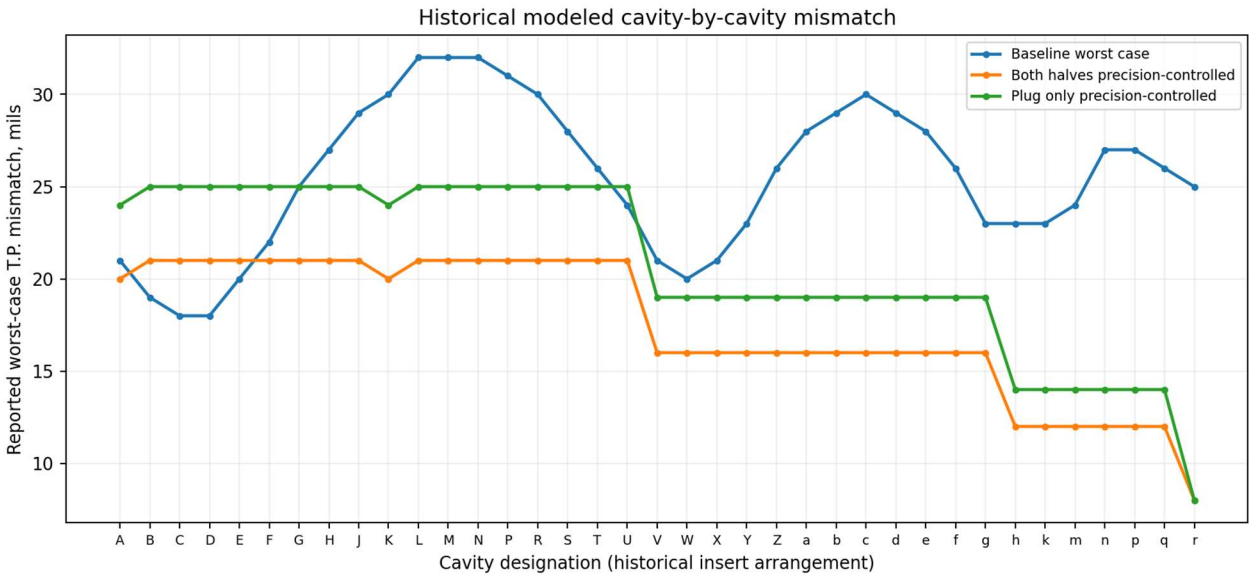


Figure 2. Replotted cavity-by-cavity reported mismatch from S2, S3 and S4. The plotted entries are historical rounded table values, with no recalculation of the modeling method.

6. Optical-terminus compliance and engagement geometry

The mechanical tolerance stack must be assessed against the actual contact’s self-alignment provisions: lateral float in the installed cavity, angular freedom from the internal contact mechanism, lead-in capture geometry of the alignment sleeve, and spring travel during final mate. The source investigation reported contact angular freedom of approximately 0.7°, localized nominal lateral movement of about 0.006 in for the pin and 0.008 in for the guide-sleeve region, and an illustrative pre-engagement lead-in capture offset of approximately 0.026 in.

These are configuration-specific historical geometry estimates, not guaranteed limits for all MIL-PRF-29504 termini, and the original documentation did not establish a probability of satisfactory engagement at the maximum lead-in offset. Critically, the lead-in chamfer’s transient capture capability must not be equated to the permissible continuous misalignment of a fully mated optical contact.

There are three separate margins: (1) capture before engagement, (2) available radial self-centering displacement at full mate and (3) retained axial spring force with acceptable endface loading. Restricting optical-contact clearances to compensate for poorly controlled shell registration may make the system worse by consuming necessary compliance. The preferred approach is to improve shell/insert registration and preserve the designed terminus movement mechanisms.

7. Mechanical misalignment is not optical core offset

Although cable link insertion loss is ultimately measured optically, cavity true position is only an upstream mechanical driver. The optical guide sleeve and spring-loaded terminus can correct a portion of the initial cavity displacement. Any residual side load, tilt, ferrule mis-seating, endface non-contact or deformation may affect optical throughput and return loss. Core eccentricity, endface geometry and contamination remain independent optical factors.

For an ideal Gaussian single-mode coupling model with identical field radii w and actual lateral core offset δ , $\eta \approx \exp[-(\delta/w)^2]$, giving insertion loss $IL \approx 4.343(\delta/w)^2$ dB. This relationship is included to distinguish final fiber-core alignment from shell-level geometry. Historical shell cavity offsets may not be inserted directly for δ : that would neglect the self-centering mating system and substantially overstate loss.

8. Engineering controls for stable random-mate performance

Priority	Control or verification	Reason
1	Constrain key/keyway angular location relative to the shell axis	Limits systematic rotation of the installed cavity pattern

2	Manage functional key widths and engagement play	Reduces rotational freedom after partial/full mate
3	Control mating shell diameters and assembly alignment	Reduces transverse displacement and tilt
4	Locate and inspect installed insert cavities from keyway datum	Closes the shell-to-insert datum chain
5	Preserve ferrule alignment-sleeve capture and terminus compliance	Maintains contact self-alignment and axial spring force
6	Test multiple channels at multiple mating conditions	Detects coupling-nut and shell registration sensitivity
7	Compare multiple mating partners and orientation extremes	Captures random-mate worst-case and production variability

One historical engineering proposal combined tighter angular key/keyway tolerances, approximately halved dimensional tolerance ranges for key/keyway widths, dedicated insert-orientation fixtures and precision-machined corrosion-resistant shells. These were design measures examined in the archived analysis; they should not be presented as current XiOptics manufacturing practices or as automatically qualified substitutions. Material or geometry changes require contemporary specification assessment, compatibility evaluation and approval under the applicable program.

9. Verification program for a modern connector design

A new evaluation should use complete metrology of the two shell keyway datum systems and every installed cavity position; obtain actual within-lot and between-lot distributions; mate several sample plug/receptacle populations; record channel-level insertion and return loss at defined coupling states; and repeat after temperature, vibration and mating-cycle conditioning. The study should include both baseline and precision-controlled shells and compare outer-ring versus inner-ring channel behavior.

Recommended measurements: (i) relative rotational free play at controlled coupling conditions; (ii) shell relative translational movement; (iii) installed cavity x/y and diametral true position referenced to the shell datum frame; (iv) contact float and spring axial travel; (v) insertion loss per channel in dB before, at, and after full coupling; (vi) return loss and stability versus minor mechanical perturbation; (vii) dimensional and optical behavior after environmental conditioning. This closes the causal loop from shell geometry to observed optical performance.

10. Conclusions

The key systems-level lesson is that the geometric quality of individual ferrules cannot compensate indefinitely for poor plug-to-receptacle registration. Rotational clearance of the cylindrical shells produces radial-position-dependent cavity displacement, and peripheral optical channels carry the greatest sensitivity. Controlled keyway angular location, functional mating clearance and insert-to-shell indexing can reduce the initial offset that the optical contact must absorb.

In the archived dimensional model, precision-control of both mating halves gave a lower reported average cavity mismatch than controlling the plug alone. This emphasizes the full mating interface rather than any single shell component. Proper contact float and guide-sleeve function should be retained while shell and cavity alignment errors are reduced. Ultimately, the mechanical improvements must be correlated with modern measured optical performance before claims of reduced insertion loss or improved qualification are made.

Technical data provenance and limitations

Tables in the following appendices are transcriptions of the numerical cavity-by-cavity model printed in a historical 2003 connector dimensional-analysis report obtained for development use. Values are reproduced in a new, readable XiOptics table format by user request; original company marks, proprietary title blocks, source-specific line illustrations and historical corporate claims are not carried into this document. This revision is not evidence that XiOptics independently performed the 2003 modeling or the historical tests. Source data use inches; 0.001 inch = 1 mil. Values in the T.P. columns are rounded as published. An image-level transcription review and verification against the native original calculation workbook are recommended before using the tables as controlled design inputs.

The historical report listed durability and optical testing as future work and contained no completed optical-versus-mechanical correlation table. Therefore neither the original report nor this rewrite independently proves a specified insertion-loss benefit, a universal compatibility claim or any current qualification status.

Appendix A — Consolidated cavity-by-cavity results

All 37 cavity designations from the historical insert model are retained. Columns S2, S3 and S4 report the original rounded consolidated worst-case true-position mismatch in inches. Improvement shown is newly computed from the displayed rounded S2 and S3 numbers for ease of reading; it is distinct from the original model's improvement-column values.

Cavity	S2 (in)	S3 (in)	S4 (in)	S2→S3 from rounded values
A	0.021	0.020	0.024	4.8%
B	0.019	0.021	0.025	-10.5%
C	0.018	0.021	0.025	-16.7%
D	0.018	0.021	0.025	-16.7%
E	0.020	0.021	0.025	-5.0%
F	0.022	0.021	0.025	4.5%
G	0.025	0.021	0.025	16.0%
H	0.027	0.021	0.025	22.2%
J	0.029	0.021	0.025	27.6%
K	0.030	0.020	0.024	33.3%
L	0.032	0.021	0.025	34.4%
M	0.032	0.021	0.025	34.4%
N	0.032	0.021	0.025	34.4%
P	0.031	0.021	0.025	32.3%
R	0.030	0.021	0.025	30.0%
S	0.028	0.021	0.025	25.0%
T	0.026	0.021	0.025	19.2%
U	0.024	0.021	0.025	12.5%
V	0.021	0.016	0.019	23.8%
W	0.020	0.016	0.019	20.0%
X	0.021	0.016	0.019	23.8%
Y	0.023	0.016	0.019	30.4%
Z	0.026	0.016	0.019	38.5%
a	0.028	0.016	0.019	42.9%
b	0.029	0.016	0.019	44.8%
c	0.030	0.016	0.019	46.7%
d	0.029	0.016	0.019	44.8%
e	0.028	0.016	0.019	42.9%
f	0.026	0.016	0.019	38.5%
g	0.023	0.016	0.019	30.4%
h	0.023	0.012	0.014	47.8%
k	0.023	0.012	0.014	47.8%
m	0.024	0.012	0.014	50.0%
n	0.027	0.012	0.014	55.6%
p	0.027	0.012	0.014	55.6%
q	0.026	0.012	0.014	53.8%
r	0.025	0.008	0.008	68.0%

As printed in the historical study, scenario mean values are S2 = 0.0254 in, S3 = 0.0175 in and S4 = 0.0208 in. These source summary values should be cited instead of recomputed means of displayed three-decimal-per-inch tabular outputs.

Appendix B / S2 baseline worst case — Detailed reported cavity components

Historical scenario numerical table as printed on source page 6. X-Δ and Y-Δ are documented planar cavity pattern offsets in inches. Socket T.P. and Pin T.P. are the documented historical component allowances, each 0.0040 in in this case. Total T.P. is the reported consolidated position-mismatch metric. The original calculation algorithm cannot be fully reproduced from the printed rounded fields alone.

Cavity	X-Δ (in)	Y-Δ (in)	Socket T.P.	Pin T.P.	Reported total T.P.
A	0.0027	0.0060	0.0040	0.0040	0.021
B	0.0027	0.0047	0.0040	0.0040	0.019
C	0.0033	0.0037	0.0040	0.0040	0.018
D	0.0043	0.0023	0.0040	0.0040	0.018
E	0.0054	0.0025	0.0040	0.0040	0.020
F	0.0066	0.0025	0.0040	0.0040	0.022
G	0.0077	0.0023	0.0040	0.0040	0.025
H	0.0087	0.0037	0.0040	0.0040	0.027
J	0.0093	0.0047	0.0040	0.0040	0.029
K	0.0093	0.0060	0.0040	0.0040	0.030
L	0.0093	0.0073	0.0040	0.0040	0.032
M	0.0087	0.0083	0.0040	0.0040	0.032
N	0.0078	0.0091	0.0040	0.0040	0.032
P	0.0066	0.0095	0.0040	0.0040	0.031
R	0.0054	0.0095	0.0040	0.0040	0.030
S	0.0043	0.0091	0.0040	0.0040	0.028
T	0.0033	0.0083	0.0040	0.0040	0.026
U	0.0027	0.0073	0.0040	0.0040	0.024
V	0.0038	0.0054	0.0040	0.0040	0.021
W	0.0044	0.0043	0.0040	0.0040	0.020
X	0.0054	0.0037	0.0040	0.0040	0.021
Y	0.0066	0.0037	0.0040	0.0040	0.023
Z	0.0076	0.0043	0.0040	0.0040	0.026
a	0.0082	0.0054	0.0040	0.0040	0.028
b	0.0082	0.0066	0.0040	0.0040	0.029
c	0.0077	0.0077	0.0040	0.0040	0.030
d	0.0066	0.0083	0.0040	0.0040	0.029
e	0.0054	0.0083	0.0040	0.0040	0.028
f	0.0044	0.0077	0.0040	0.0040	0.026
g	0.0038	0.0066	0.0040	0.0040	0.023
h	0.0048	0.0060	0.0040	0.0040	0.023
k	0.0054	0.0043	0.0040	0.0040	0.023
m	0.0066	0.0043	0.0040	0.0040	0.024
n	0.0072	0.0060	0.0040	0.0040	0.027
p	0.0066	0.0071	0.0040	0.0040	0.027
q	0.0054	0.0071	0.0040	0.0040	0.026
r	0.0060	0.0060	0.0040	0.0040	0.025

Transcription note: source column headers and numerical precision are retained wherever legible; the documented T.P. result is not inferred from simply adding the visible values. The model is illustrative for the historical 25-37 configuration only.

Appendix C / S3 precision-controlled pair — Detailed reported cavity components

Historical scenario numerical table as printed on source page 8. X-Δ and Y-Δ are documented planar cavity pattern offsets in inches. Socket T.P. and Pin T.P. are the documented historical component allowances, each 0.0040 in in this case. Total T.P. is the reported consolidated position-mismatch metric. The original calculation algorithm cannot be fully reproduced from the printed rounded fields alone.

Cavity	X-Δ (in)	Y-Δ (in)	Socket T.P.	Pin T.P.	Reported total T.P.
A	0.0059	0.0000	0.0040	0.0040	0.020
B	0.0059	0.0023	0.0040	0.0040	0.021
C	0.0048	0.0041	0.0040	0.0040	0.021
D	0.0031	0.0055	0.0040	0.0040	0.021
E	0.0011	0.0062	0.0040	0.0040	0.021
F	0.0010	0.0062	0.0040	0.0040	0.021
G	0.0031	0.0055	0.0040	0.0040	0.021
H	0.0047	0.0042	0.0040	0.0040	0.021
J	0.0058	0.0023	0.0040	0.0040	0.021
K	0.0059	0.0000	0.0040	0.0040	0.020
L	0.0059	0.0023	0.0040	0.0040	0.021
M	0.0048	0.0041	0.0040	0.0040	0.021
N	0.0031	0.0055	0.0040	0.0040	0.021
P	0.0011	0.0062	0.0040	0.0040	0.021
R	0.0010	0.0062	0.0040	0.0040	0.021
S	0.0031	0.0055	0.0040	0.0040	0.021
T	0.0047	0.0042	0.0040	0.0040	0.021
U	0.0058	0.0023	0.0040	0.0040	0.021
V	0.0040	0.0010	0.0040	0.0040	0.016
W	0.0023	0.0030	0.0040	0.0040	0.016
X	0.0011	0.0040	0.0040	0.0040	0.016
Y	0.0010	0.0041	0.0040	0.0040	0.016
Z	0.0023	0.0030	0.0040	0.0040	0.016
a	0.0040	0.0011	0.0040	0.0040	0.016
b	0.0040	0.0010	0.0040	0.0040	0.016
c	0.0023	0.0030	0.0040	0.0040	0.016
d	0.0011	0.0040	0.0040	0.0040	0.016
e	0.0010	0.0041	0.0040	0.0040	0.016
f	0.0023	0.0030	0.0040	0.0040	0.016
g	0.0040	0.0011	0.0040	0.0040	0.016
h	0.0021	0.0000	0.0040	0.0040	0.012
k	0.0011	0.0013	0.0040	0.0040	0.012
m	0.0011	0.0013	0.0040	0.0040	0.012
n	0.0021	0.0000	0.0040	0.0040	0.012
p	0.0011	0.0013	0.0040	0.0040	0.012
q	0.0011	0.0013	0.0040	0.0040	0.012
r	0.0000	0.0000	0.0040	0.0040	0.008

Transcription note: source column headers and numerical precision are retained wherever legible; the documented T.P. result is not inferred from simply adding the visible values. The model is illustrative for the historical 25-37 configuration only.

Appendix D / S4 precision-controlled plug — Detailed reported cavity components

Historical scenario numerical table as printed on source page 11. X-Δ and Y-Δ are documented planar cavity pattern offsets in inches. Socket T.P. and Pin T.P. are the documented historical component allowances, each 0.0040 in in this case. Total T.P. is the reported consolidated position-mismatch metric. The original calculation algorithm cannot be fully reproduced from the printed rounded fields alone.

Cavity	X-Δ (in)	Y-Δ (in)	Socket T.P.	Pin T.P.	Reported total T.P.
A	0.0073	0.0001	0.0040	0.0040	0.024
B	0.0073	0.0031	0.0040	0.0040	0.025
C	0.0065	0.0055	0.0040	0.0040	0.025
D	0.0042	0.0074	0.0040	0.0040	0.025
E	0.0015	0.0084	0.0040	0.0040	0.025
F	0.0014	0.0084	0.0040	0.0040	0.025
G	0.0041	0.0074	0.0040	0.0040	0.025
H	0.0064	0.0056	0.0040	0.0040	0.025
J	0.0073	0.0032	0.0040	0.0040	0.025
K	0.0079	0.0001	0.0040	0.0040	0.024
L	0.0073	0.0031	0.0040	0.0040	0.025
M	0.0065	0.0055	0.0040	0.0040	0.025
N	0.0042	0.0074	0.0040	0.0040	0.025
P	0.0015	0.0084	0.0040	0.0040	0.025
R	0.0014	0.0084	0.0040	0.0040	0.025
S	0.0041	0.0074	0.0040	0.0040	0.025
T	0.0064	0.0056	0.0040	0.0040	0.025
U	0.0073	0.0032	0.0040	0.0040	0.025
V	0.0054	0.0014	0.0040	0.0040	0.019
W	0.0040	0.0040	0.0040	0.0040	0.019
X	0.0015	0.0055	0.0040	0.0040	0.019
Y	0.0014	0.0055	0.0040	0.0040	0.019
Z	0.0033	0.0041	0.0040	0.0040	0.019
a	0.0054	0.0015	0.0040	0.0040	0.019
b	0.0054	0.0014	0.0040	0.0040	0.019
c	0.0040	0.0040	0.0040	0.0040	0.019
d	0.0015	0.0055	0.0040	0.0040	0.019
e	0.0014	0.0055	0.0040	0.0040	0.019
f	0.0033	0.0041	0.0040	0.0040	0.019
g	0.0054	0.0015	0.0040	0.0040	0.019
h	0.0023	0.0000	0.0040	0.0040	0.014
k	0.0015	0.0026	0.0040	0.0040	0.014
m	0.0014	0.0026	0.0040	0.0040	0.014
n	0.0023	0.0000	0.0040	0.0040	0.014
p	0.0015	0.0026	0.0040	0.0040	0.014
q	0.0014	0.0026	0.0040	0.0040	0.014
r	0.0000	0.0000	0.0040	0.0040	0.008

Transcription note: source column headers and numerical precision are retained wherever legible; the documented T.P. result is not inferred from simply adding the visible values. The model is illustrative for the historical 25-37 configuration only.

Appendix E — Historical modeling assumptions and limitations

Source case	Key/keyway and insert assumptions	Model output
S1	Zero angular play and common shell axis; idealized most favorable key registration	Mean mismatch 0.0068 in; cavity table not legible in archived figure
S2	Key/keyway position tolerance modeled within 0.009 in T.P. with 0.004 in + 0.005 in allowances; socket/pin cavity allowance 0.004 in each	Mean mismatch 0.0254 in
S3	Key/keyway dimensional ranges reduced by approximately one-half; key/keyway positional T.P. within 0.0045 in with base/bonus terms; both halves precision-controlled	Mean mismatch 0.0175 in
S4	Same basic angular/width control concept applied to the plug only; mating half remains baseline	Mean mismatch 0.0208 in

The actual wording of the historical model alternates between angular tolerances stated in degrees and equivalent/associated true-position allowances stated in inches. These cannot be interchanged without the effective datum radius and specific GD&T callout. For contemporary design, the engineering drawing and current MIL-DTL-38999 requirement take precedence.

The idealized S1 value is preserved only as the printed scenario-average result. No complete legible per-cavity numeric table for S1 is available in the scanned copy. The paper deliberately does not fabricate these missing cavity values.

Appendix F — Modern design review checklist

- Confirm shell size and exact insert arrangement against current controlled slash sheets.
- Define plug and receptacle datum frames, clocking and major keyway measurement procedures.
- Specify actual key/keyway width and angular positional tolerances with appropriate MMC/LMC modifiers.
- Measure installed insert cavity coordinates rather than insert-only dimensions.
- Distinguish worst-case mechanical stack from production occurrence statistics.
- Verify optical contact pre-engagement capture range, installed float, angularity and spring travel.
- Correlate outer-ring optical channels against shell position and coupling nut state.
- Demonstrate full interchangeability through cross-mating and environmental testing.
- Qualify changes against current procurement, program and standard requirements.

References

[1] MIL-DTL-38999, Series III, applicable current edition and slash sheets; controlling engineering document for shell dimensions and mating interfaces.

[2] MIL-PRF-29504, applicable current specification and contact detail sheets; controlling optical-terminus dimensional and performance framework.

[3] Historical 37-cavity geometric tolerance dataset acquired for engineering development (2003); summary and rows presented as legacy dimensional model data, not current product qualification evidence.