Spring Force Requirements for MPO Connectors

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Abstract

Stringent endface geometry requirements are necessary to achieve physical contact in fiber optic connections. Previous studies of MT ferrule endface geometry requirements have focused on single 12 fiber arrays. Standardized spring forces and endface geometries may become insufficient to maintain physical contact for higher fiber counts.

This paper examines the critical parameters, including the spring force and ferrule geometry, needed to achieve physical contact for MT-16 based ferrules and to ensure optimal insertion loss and return loss performance for mated connector assemblies.

Results indicate that multimode flat and angled interfaces, with fiber counts of 16 or greater, can benefit from spring forces higher than 12 fiber ferrules. Single-mode angled interfaces, with 16 fibers in a single array, present additional core alignment challenges due to the y-directional shift that occurs when mating. For these connectors, 10N spring force may be sufficient.

Keywords: MT ferrule; endface geometry; spring force; physical contact; insertion loss; singlemode; multimode

1. Introduction

The proliferation of transceiver formats supporting higher bandwidth links with aggregated fibers in a single device has resulted in transceiver modules supporting as many as 16 fibers within a single connector format. The MPO-16 ferrule format was originally standardized by Telecommunications Industry Association in 2015 with the release of TIA 604-18 [1]. Initial applications for high density trunk cabling infrastructure with fiber rows of 16 are now complemented with 400G SR8 transceivers accepting the MPO-16 connector format supporting 100m links with multimode technology. In addition, the industry is now looking forward to deploy the latest single-mode (SM) lane technology to support 800G link designs with the latest SM Angled Physical Contact (APC) format.

Historically, the polish angle on multi-fiber MPO cables has been flat for multimode (MM) link transmission and angled at eight degrees (APC) for SM link transmission. This industry de facto standard was driven by early application requirements. Telecom Central Office use for early SM MPO applications demanded optimal return loss and drove SM MPO connectors to only be offered in APC variants. Multimode, on the other hand, has been historically used within telecom routers or in data communication links where the return loss requirement of better than 20dB has been ample. However, emerging high speed multimode links are utilizing more advanced modulation formats such as Pulse Amplitude Modulation (e.g., PAM4) in place of NRZ modulation. Signal to Noise Ratio (SNR) dependence on pulse amplitude makes the signal more prone multi-path interference problems, therefore driving multimode return loss requirements to new levels.

Previous studies on obtaining physical contact of fiber tips in multi-fiber ferrules have highlighted the interdependence on endface geometry, the quantity of fibers per ferrule, and connector spring force. Endface geometry inaccuracies due to fiber tip protrusion variation, endface skew relative to alignment datums, endface shape and fiber tip radii are overcome with the applied connector mating force and elastic deformation of the entire system [2, 3]. Furthermore, as fiber counts increase in a single ferrule, the endface geometry precision and/or connector spring force must increase to ensure physical contact of the fiber tips. Industry standardization efforts have resulted in higher spring force requirements for higher fiber count ferrule designs as detailed in TIA 604-5-F [4].

In addition to the relationship between physical contact on polish quality and fiber count, APC designs also introduce interdependence on ferrule design and connector spring force. When APC MT ferrules are mated, there is translation between the two ferrules induced by the polish angle, as shown in Figure 1.

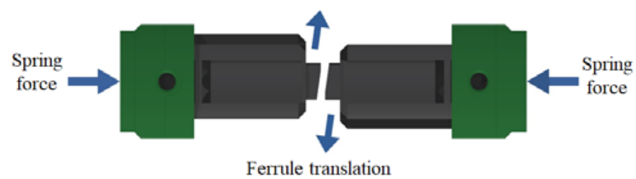


Figure 1. Ferrule translation for angled connections during mating

This translation is due to clearance between the guide pins and guide pin bores, guide pin bore pitch variation, and elastic deformation of the system. As spring force is increased, the amount of translation between the two ferrules increases and therefore must be accommodated with an offset of the fiber cores relative to the alignment features [5].

2. Theoretical Analysis

Successful performance of physical contact based optical connectors depends on reliable fiber tip engagement with no air gap while the connectors are properly mated. Physical contact must be maintained through initial coupling, as well as, through the life of the product, which is simulated through environmental testing. Loss of physical contact of the fiber tips results in optical performance degradation due to Fresnel reflection effects [6]. Insertion loss performance with multi-fiber ferrules which does not match predicted loss due to fiber and ferrule geometry can often be attributed to air gaps or poor fiber tip physical contact. Different methods can be used to determine the presence of or lack of fiber tip physical contact. On average, the increase in loss due to a small airgap can be approximated to 0.3 dB, but can vary from 0 to 0.6 dB depending on whether the reflection creates a constructive or destructive interference pattern.

A common method to verify high insertion loss due to Fresnel reflections is to measure return loss. The return loss due to a Fresnel reflection on a flat polished fiber tip will be <15dB [6]. For flat polished ferrules with acceptable physical contact, the return loss will be >25dB, resulting in a simple measurement method to analyze for the presence of an air gap.

Similarly, a method used to validate physical contact consists of measuring the insertion loss taken at two wavelengths. For example, the single-mode insertion loss ratio due to fiber core lateral offset between 1310 nm and 1550 nm calculated as a result of differences in mode field diameter is approximately 0.78 [6]. As a result, insertion loss data due to only fiber core lateral offset, with known physical contact of the fiber tips, will fall on a line with a slope of 0.78. Data points far from this line can be an indicator of air gaps between the fibers, angular offset between the two mated fibers or mode field diameter mismatch between the two mated fibers.

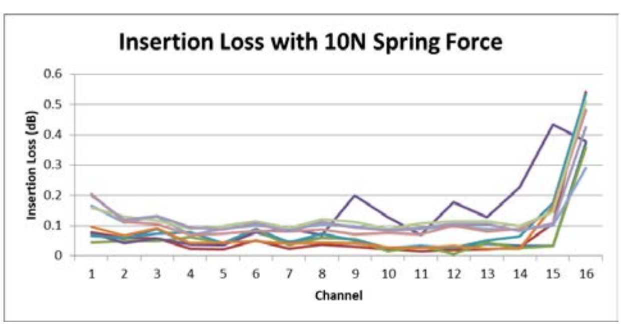
3. Empirical Results

Endface geometry requirements and optical performance for traditional MT ferrules with 12 fiber arrays have been analyzed for over 20 years. While the requirements for 12 fiber arrays are well understood, the emergence of new ferrule fiber counts necessitates additional analysis to comprehend the impact of increased fiber counts on these requirements. It is important to choose a spring force that supports reliable connections and reasonable endface geometry limits. During these experiments, the following variants were tested for analysis:

- 16 fiber MM PC with 10N spring force
- 16 fiber MM PC with 20N spring force
- 16 fiber MM APC with 20N spring force
- 16 fiber SM PC with 10N spring force
- 16 fiber SM PC with 20N spring force
- 16 fiber SM APC with 10N spring force

3.1 Multimode Flat Physical Contact

The initial study began with 16 fiber multimode (MM) flat polished MT ferrules. For this testing, due to the flat polished endface, y-offset is not a factor, so the focus was strictly on achieving physical contact of the fiber tips. A total of ten MPO jumper samples were terminated and polished using conventional MT ferrule processes for each 10N and 20N spring forces, and endface geometry measurements were performed. Using 10N and 20N spring forces with the same ferrule lot, polishing regimen and requirements, insertion loss and return loss measurements were taken. In Figure 2 and Figure 3, 10N and 20N results are shown, respectively.



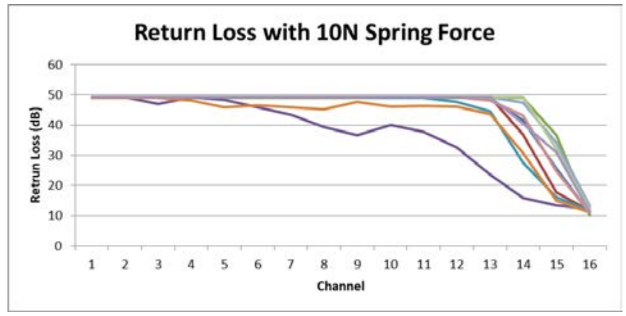


Figure 2. 16 fiber MM PC results with 10N spring force for both insertion loss and return loss at 850nm

Figure 3. 16 fiber MM PC results with 20N spring force for both insertion loss and return loss at 850nm

The 10N samples consistently showed higher insertion losses on end channels consistent with Fresnel effects as indicated above, indicating potential lack of physical contact. Return loss measurements confirmed that the 10N spring force was not sufficient to overcome endface geometry and maintain physical contact. Endface geometry measurements, as shown in Table 1, confirm that both 10N and 20N samples had similar endface geometry, demonstrating that similar geometries require higher spring forces to produce reliable physical contact.

Table 1. Endface geometry data for 16 fiber MM PC

	Spring force	Ferrule X angle (°)	Ferrule Y angle (°)	Minus coplanarity (nm)	Fiber height 1 (nm)	Fiber height 9 (nm)	Fiber height 16 (nm)
Avg	10N	0.01	0.09	206	1794	1988	1673
Stdev		0.04	0.02	30	111	124	103
Avg	20N	0.04	0.09	206	1812	2010	1689
Stdev		0.05	0.03	23	140	94	95

3.2 Multimode Angled Physical Contact for Improved Return Loss Applications

For 16 fiber multimode angled physical contact (APC) MT ferrules, the ferrule fiber bore position must be shifted to compensate for the y-offset translation that occurs in the mating process as discussed and shown in Figure 1 above.

This y-offset position is based on the guide bore diameter, guide pin diameter, guide pin pitch relationship, and the deformation constant of the MT ferrule material. Since the amount of elastic deformation will be different for multiple spring forces, the y-offset must be adjusted for the particular spring force tested.

Based on the results from the multimode PC experiment, 20 mated pairs of 16 fiber multimode APC MT ferrule samples with 20N spring force MPO connectors were terminated and exposed to the following environmental test regimen:

- Low temperature: -10°C for 96 hours
- Thermal Aging: 60°C for 96 hours
- Humidity Aging: 40 ±2°C at 90-95% RH for 96 hours

Table 2 summarizes the results from the 16 fiber multimode APC testing.

Table 2. Environmental results for 16 fiber MM APC with 20N spring force

SPECIFICATION	PERFORMANCE	850nm (dB)	1310nm (dB)
New Product Test	IL $_{Max}$	0.17	0.33
	IL $_{Avg}$	0.06	0.15
	RL $_{Avg}$	-50	-54
Post Chamber	Delta to Initial IL $_{Max}$	0.13	0.19
	Delta to Initial IL $_{Avg}$	0.02	0.03
	IL $_{Max}$	0.12	0.25
	IL $_{Avg}$	0.05	0.11
	RL $_{Avg}$	-50	-53

Results indicate excellent stability and performance throughout the environmental test regimen for both insertion loss and return loss performance without highly restricting endface geometry, as shown in Table 3.

Table 3. Endface geometry for 16 fiber MM APC

	Ferrule X angle (°)	Ferrule Y angle (°)	Minus coplanarity (nm)	Fiber height 1 (nm)	Fiber height 8 (nm)	Fiber height 9 (nm)	Fiber height 16 (nm)
Avg	0.02	8.08	199	1760	1992	1988	1680
Stdev	0.05	0.08	33	184	121	120	151

3.3 Singlemode Flat Physical Contact

As with the multimode testing, flat PC connections were tested on SM to understand if the physical contact behaviors for SM are similar to multimode. Single mode polished fibers have a simplified, spherical fiber tip shape when compared to MM which can result in physical contact at lower forces. Incremental spring force was carefully applied to the flat polished 16 fiber ferrules. The flat polished fiber tips provide a clear indication of physical contact when measuring return loss. Measurements were made on three mated pairs at spring forces of 4N to 10N in 1N increments to determine when physical contact was achieved. Return loss of greater than 25dB was used as a safe indication of reliable physical contact. In Table 4, the results of measurements are shown, where white cells represent contact and gray cells represent lack of contact.

For these mated pairs, the data indicates that stable physical contact is achieved at 10N spring force including the end channels where protrusion levels are typically lower. 9.8N +/- 2N is the standardized spring force used for traditional 12 fiber, single row MPO connectors [4] and a candidate for the single-mode MPO-16 format.

As with the previous experiments, endface geometry measurements were acquired on each connector in the mated pairs; results are shown in Table 5.

Table 4. Physical contact for 16 fiber SM PC, where channels exhibiting non-contact are indicated in gray

Mated Pair	Spring Force	Channel															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	4N																
	5N																
	6N																
	7N																
	8N																
	9N																
	10N																
2	4N																
	5N																
	6N																
	7N																
	8N																
	9N																
	10N																
3	4N																
	5N																
	6N																
	7N																
	8N																
	9N																
	10N																

Table 5. Endface geometry for 16 fiber SM PC

Serial number	Ferrule X angle (°)	Ferrule Y angle (°)	Minus coplanarity (nm)	Fiber height 1 (nm)	Fiber height 9 (nm)	Fiber height 16 (nm)
1a	-0.10	0.00	159	2142	2420	2160
1b	-0.06	0.02	216	2136	2464	2117
2a	-0.10	0.03	243	2162	2512	2111
2b	-0.09	0.00	245	2279	2596	2185
3a	-0.01	0.01	224	2218	2596	2245
3b	-0.01	-0.01	194	2169	2504	2197

3.4 Singlemode Angled Physical Contact

Following the successful results with the 16 fiber multimode APC MT ferrules with 20N MPO spring forces and validation of SM PC at 10N, the next step was to validate the acceptable spring force for 16 fiber SM APC MT ferrules. Within the International Electrotechnical Commission (IEC), discussion continues on this topic as multiple manufacturers produce and test various MT ferrule Y fiber hole position offsets with spring forces in order to identify the appropriate force for SM APC. Singlemode APC ferrules are more sensitive to the changes in spring force due to the smaller core size. If the y-offset is not correctly matched to the chosen spring force, the fiber cores can slip past each other, exhibiting significantly higher insertion losses. Figure 4 shows insertion loss data measured at 1310nm and 1550nm compared to the theoretical ratio assuming the insertion loss is due to only transverse fiber core offset. The data all falls within +/-0.1 dB of the line and supports the premise that the fibers have physical contact at 10N.

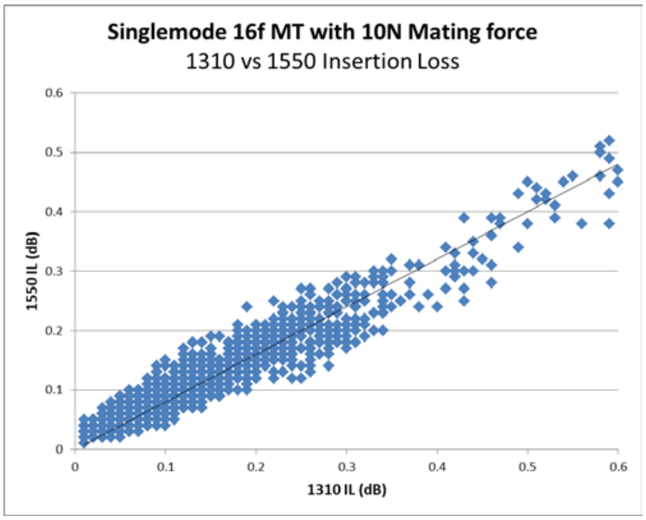


Figure 4. 16 fiber SM 1310nm vs 1550nm insertion loss results with 10N spring force

4. Conclusions

Experiments were completed to quantify spring force requirements to achieve physical contact for multimode and singlemode 16 fiber MT ferrules with typical polished endface geometry. Results indicate that 16 fiber multimode ferrules may require more than 10N to achieve physical contact. The standardized, 20N spring force was used to produce acceptable performance for both flat and APC multimode ferrules. APC 16 fiber ferrules resulted in stable performance for applications requiring return loss >50dB. Singlemode flat polished 16 fiber MT assemblies obtained clear physical contact at below the standardized spring force for 12F MPO connectors. This study indicates that the ultimate standardized spring force for low-loss, singlemode APC MT-16 applications could be harmonized to the 9.8N nominal force. Future work will require defining endface geometry limits necessary for physical contact at any standardized connector forces.

5. References

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6. Authors

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