

Parametric Mating Force Model for Partially-filled Connectors

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ABSTRACT

A predictive model for the mating forces of hand-plug connectors has been developed; it calculates the forces in a connector that has empty cavities instead of terminals in every position. Force data is needed as a check to see if connectors meet the latest ergonomic requirements in their as-built configurations. Historically, force data has been generated from physical testing since prior predictive models were not accurate enough. Testing is expensive and slow so a more advanced and accurate model was created. The model presented in this paper is accurate enough to replace mechanical force testing of partially-filled hand-plug connectors.

INTRODUCTION

The rules for what connector mating forces are acceptable changed greatly in 2003, when the USCAR-25 specification was released. Lower force limits were required made when research demonstrated that connectors with lower mating forces have benefits of: 1) lower risk of a repetitive stress injury at assembly and 2) increased probability of being mated in the fully-locked position. The improvement was so compelling that the USCAR-25 requirement has been applied to existing connectors, instead of only new connectors as would be done with less compelling justification. It is important to emphasize that matching the connector mating force to modern ergonomic standards helps both assembly ease *and* assembly quality; connectors with high mating forces do not always get mated fully. In a previous unpublished study, the following correlation data was found:

- 98% positive correlation between connector mating effort and disconnect rates when efforts exceeded 111N
- 67% positive correlation between connector effort and disconnect rates for connectors with mating efforts between 76 and 110N.
- No significant correlation between mating force and disconnects for connectors under 75N. **Note:** all values are after de-rating for grasp and conditions.

The USCAR-25 spec release drove a thorough reassessment study to be done on the full installed base of connectors; any connector deemed unacceptable to the requirements would have to be fixed by: a) using two smaller connectors to replace the one high-force connector or, b) retool with a modern low-force terminal system. Both options are expensive so care was given to make sure that no connector was needlessly rejected. The way that an unnecessary connector re-tooling may happen was having a fully-loaded connector that failed and it was missed that it was not fully-loaded in the application. In this case, the force would be less and the connector would possibly be acceptable. The research presented in this paper presents a method to accurately, but conservatively, characterize the mating force of a connector with some circuits not used, thereby eliminating the error and avoiding needless expense.

Before discussing the parameters of mating force, a brief review of the driving specification will be helpful: In ideal conditions, a connector is allowed a mating force of 75N. As the ability to grasp or access a connector deteriorates, the limit can drop to as low as 24N. The size and shape of the connector and the conditions of the assembly operation are both factors. In practice, we initially found that 20% of connectors failed the USCAR-25 criteria. For a vehicle program with 100 unique connector designs, this implies retooling 20 connectors—which is significantly more than typical. The motivation to minimize retooling was high and one big opportunity to avoid retooling was reclaiming connectors that are wrongly rejected. We learned that a significant fraction of the otherwise rejected connectors could again be used—with the limitation that only a defined number of circuits could be used. Given how wire harnesses are designed, many connectors are not full and the opportunity was obvious.

The “brute force” method of measuring the mating force of the specific reduced-wire configurations needed was done initially, using standard tensile test equipment as called out in the test specification, SAE/USCAR-2. In a short time this method, which requires time consuming sample preparation, was found to result in unacceptable delays and lab charges. The benefit of a robust method to calculate the mating force of a partially-filled connector became obvious. Initially, it was thought that a simple existing force model would work but it was not accurate enough. The initial model was a simple linear ap-

proximation of the partial force given the fully-populated force:

$$F_{\text{part}} \approx F_{\text{total}} \cdot \frac{N_{\text{used}}}{N_{\text{total}}}$$

This linear model was tested and found to be too simple to be of value; it underestimated the forces when more than half of the circuits were not used. Errors up to 30% were seen. Therefore, a study was done to determine what additional factors had to be included. Soon, a research project was started to formally develop a mating force model for partially-full connectors.

REVIEW OF ERGONOMIC REQUIREMENTS

SPECIFICATION DETAILS – Per the USCAR-25 specification (initially released in 2003), 75N is identified as the maximum force that can be applied by-hand to a single connector. De-rating factors are then included, as applicable, to compensate for the 1) finger-grip “type” needed to grasp the connector and 2) the hand-position needed to engage the connector in the actual vehicle assembly orientation. When all possibilities are considered, the 75N connector may be de-rated to as little as 24N.

Here is a hypothetical situation: a connector with a measured 50N mating force (when fully populated with terminals) was acceptable prior to USCAR-25. Now, say the connector cannot be mated with the preferred “oblique” grip and a “medial” grip is used (see definitions below). Then, per Table 1 (from USCAR-25), the 75N maximum force is reduced by a factor of 60% to 45N. Now, the 50N connector will be rejected if used fully populated. So, in the common situation where the connector is not fully populated, a re-test with the lower terminal count would be done. If the reduction in terminals accounts for a 5N reduction, the connector would be rated acceptable again and retooling avoided.

Table 1. Multiplication factor that reduces allowable mating forces dependent on grip type.

Grip Type	Multiplication Factor (%)
Oblique Grasp	100
Medial Grasp	60
Pinch	60
Press	45

Here are the four grip types involved. They are:

The oblique grasp is the most ideal grip that can be placed on a connector and is seen when the fingers wrap around the object, and the thumb overlaps the fingers. With this grasp, a person is capable of exerting the most effort.

The medial grasp involves wrapping the fingers around the object, with the thumb oriented along the line of force on the object.

The pinch grasp involves any grip that has force application at or near the finger tips, where the fingertips are opposed to the thumb, palm or side of the index finger.

The press grip involves force that can only be applied with either the thumb or the finger(s). With this grip, a person can exert only 45% of the force that they could have with an oblique grasp. For details of the de-rating process, reference the USCAR-25 specification.

MODEL DEVELOPMENT

EXISTING FORCE MODELS – Past research approaches have focused on methods of reducing terminal and connector insertion force via optimization of design [1,2,3]. These efforts concentrate on development of improved coatings applied to the contact surfaces and geometry improvements, typically to the terminal [8]. Other non-published reports [4,5] discuss methods of predicting mating forces, but their models require detailed part information for every connector system and is therefore not suitable to evaluating older parts where this information is not available. A literature search and discussion with colleagues [4,5,6] confirmed that there are no models giving a fast and accurate way of predicting the mating force reduction value as terminals are removed in a connector design. This search of prior work confirmed that a new model had to be developed; one that can predict insertion force for a connector with any number of positions remaining unused.

FACTORS TO MODEL - The following factors were considered in the development of the model:

- 1. Male to female terminal mating force (influenced by geometry of blade tips, spring rate, etc.).
- 2. Drag of perimeter seal against mating plastic (influenced by seal size, compression, and composition).
- 3. Terminal-to-terminal misalignment (known as the the array factor, accounting for misalignment between the mating terminals).
- 4. Air pressure resistance to mating connector (due to compression in a sealed connector).
- 5. Plastic to plastic drag (due mostly to lock beam deflection but there are other factors).

Two approaches were considered for how to model the force of a reduced count connector where the fully-populated force has already been measured:

- 1. Start with the total fully-loaded force and subtract the mating force per terminal times the