IMPROVED DESIGN OF END HOSE SUPPORT STRAP FOR FREIGHT CARS

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ABSTRACT

The end hose support on a freight car is a hanging strap which supports the air brake hose at the termination of the brake pipe.

Traditionally, there have been three types of end hose supports: rigid, semi-rigid and elastic. Steel, polymer, rubber and synthetic woven materials have commonly been used to make the support strap. Breakage and permanent extension at the strap happen frequently, which can cause train delays and other various train operation problems.

Previous research commissioned by the Association of American Railroads (AAR) and conducted by Lin Hua, et al, revealed that constant energy is generated by end hose separations [1]. It was found that the actual strength of the hose support was indeed the combination of its tensile strength and ability of absorbing the potential energy to reduce the impact. This finding led to the revision of the AAR's end hose support specification, S-4006-2003 [2]. The new S-4006-2008[3] connected the static tensile strength of the end hose support strap with its elasticity characteristics.

Based on the constant energy theory, an elastic support is preferred by many due to its low ultimate tensile load during an end hose separation, which makes both the strap and all the components it attaches to less stressful. This paper discusses an elastic end hose support strap design, which takes a unique approach to improve strength without significantly changing size, weight or other physical properties.

1. INTRODUCTION

The end hose support is sometimes also called a hose strap in the railroad industry. It is used for supporting railroad cars' end hose assemblies. It attaches and hangs from the bottom of the coupler and supports the end hose-gladhand assembly. The strap supports the assembly and holds it above the ground to prevent unwanted contact. Almost all the hose strap products are adjustable in length in order to suit different end-of-car arrangements so that the gladhand to rail distance will meet AAR specifications. Traditionally, there have been three types of end hose supports: rigid, semi-rigid and elastic. Steel, polymer, rubber and synthetic woven materials are commonly used to make the support strap. Figure 1 illustrates a typical end hose support strap which hangs the end hose assembly (consists of gladhand, hose and PHN fitting) from the coupler.

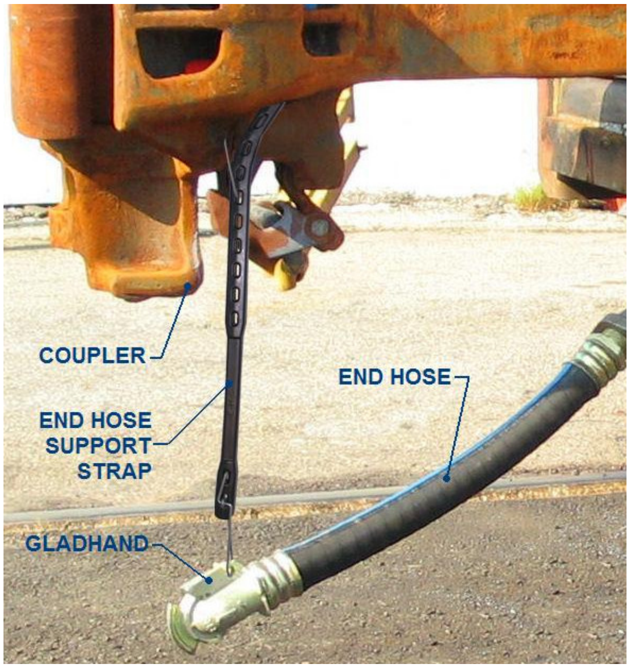

Figure 1: Hose Strap Supports End Hose

2. ULTIMATE TENSILE FORCE

During normal train operation, the end hoses of two adjacent cars are connected by gladhand couplings and the end hoses are filled with compressed air. Under this condition, the force applied to the strap and connecting components is very low, usually well below 25 lbs. However, if the gladhands are uncoupled, either intentionally or unexpectedly under the pressurized condition, the sudden impact applied to the strap, resulting from the compressed air jetting from the open gladhand can be very intense.

Figure 2: Device for simulating end hose arrangement. Hose support straps are connected to a set of load cells to monitor tensile force.

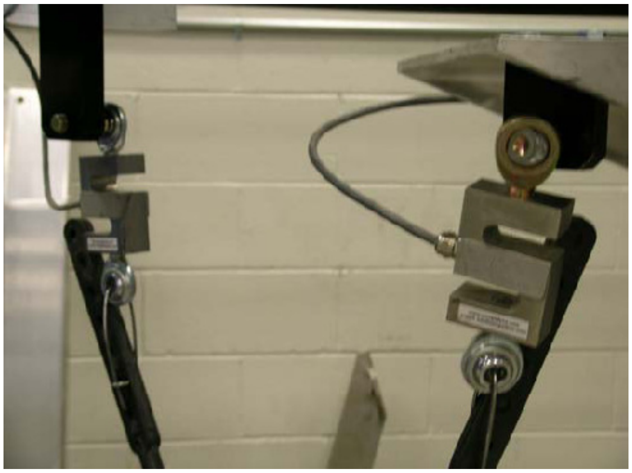

Figure 3: Detailed view of load cells

In the past, for many years, AAR Specification S-4006-2003 [2] only required hose straps to be able to lift 300 lbs or any lesser weight which would cause the strap to stretch five inches (provided that the stretch is less than one inch under 25 lbs of weight) [2]. In 2005, the AAR commissioned Strato, Inc. to perform research for studying causes for hose strap failures. A test apparatus was then built to simulate end of car arrangements and hose separations; figure 2 and 3 illustrate this device. A technical paper resulting from that research was presented at the ASME Joint Rail Conference in 2006[3]. The outcome of that research also resulted in the AAR's revision of its S-4006-2003 [2] specification. The new revision was released at the end of 2008 and mandated full implementation by November 1, 2009. According to the new maximum load, the minimum strength requirement is now connected to elasticity (stretch) of the strap. Figure 4 illustrates the new AAR maximum load requirement (This figure is a copy of AAR S-4006-2008 Fig. 4.1[3]). The new specification raised the requirement for a rigid strap to 600 lb, and 300 lb if the straps stretch more than 10 inches when the load is 300 lb.

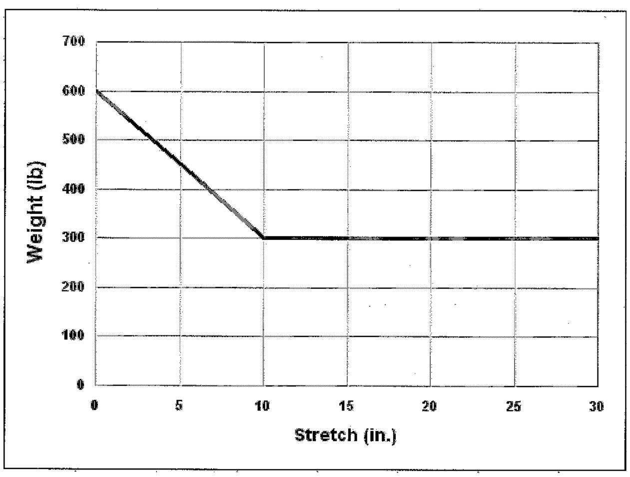

Figure 4: Minimum Tensile Strength of hose strap, per AAR S-4006-2008 [3]

The most recent experiments found that the impact energy can create over 1,000 lbs force on the supporting strap if it is highly non-elastic. Figure 5 is a chart which shows the ultimate forces resulting from 900 lb•in of impact energy. It is obvious that the elastic material, due to its ability of absorbing energy gradually, created only about 1/5 of the ultimate force as compared to the rigid material. This test result supports the potential energy theory

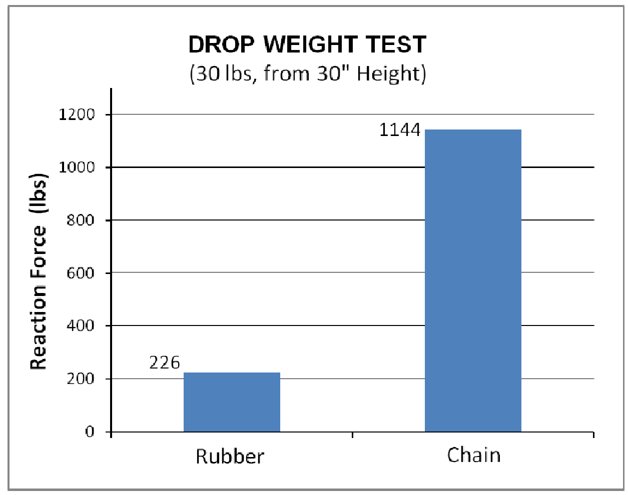

Figure 5: Ultimate force created by 900 lb•in of impact energy to elastic material (rubber) and rigid material (steel chain).

reported by L. Hua [1]. This potential energy is presented as:

$$Ep = \int_0^{X_{max}} FdX = \int_0^{X_{max}} KXdX = \frac{F_{max}^2}{2K} \quad (1)\ [1]$$

Where *Ep* is the potential energy applied to the hose strap, *F* is the tensile force resulting from this energy, *K* is the elasticity coefficient of the strap assembly and *X* is the elastic deformation. F_{max} is the ultimate tensile force. From the equation above, we can also calculate the ultimate tensile force F_{max} from a given potential energy *Ep* and elasticity coefficient *K*: [1]

$$F_{max} = \sqrt{2KEp} \quad (2)$$

For a strap which extends 10 inches under a 300 lb load, for example, the elasticity coefficient *K* equals 30 lb/inch. The actual *K* of the elastic strap used for the test shown in figure 5 is approximately 28 lb/inch. If *Ep* equals 900 lb•in, from Eq. (2), the ultimate force applied on the elastic strap is:

$$F_{max} = \sqrt{2 * 28 * 900} = 224.5 \text{ lb}$$

This is very close to the test result of 226 lb. The rigid strap showed severe permanent deformation after the impact although it had no problem lifting 600 lb as S-4006-2008[3] requires. This permanent deformation absorbed some energy and thus reduced the ultimate force and probably prevented the strap from failure. However, the permanent deformation made future removal or length adjustment of the strap very difficult, if not impossible. In addition, the 1144 lb force could possibly cause damage to other components that the strap is attached to.

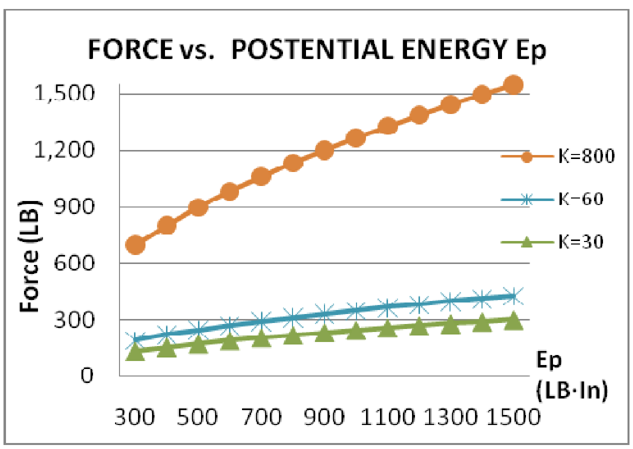

Figure 6: Ultimate tensile force vs. potential energy, calculated using different elasticity coefficient.

Figure 6 illustrates the relationship between potential energy and the ultimate tensile force which is calculated using Eq. (2). Results of three different elasticity coefficients are shown.

Because the potential energy is nearly a constant for each specific end hose arrangement and separation condition, the elasticity coefficient K plays a huge role in ultimate tensile force. It is obvious that a more rigid strap must withstand a much higher tensile force than an elastic strap. A rigid metal strap increases its tensile strength by increasing the cross-sectional size and is then considered “heavy duty”. However, it is not necessarily stronger because the cross-sectional increase inevitably increases the elasticity coefficient, which will result in an even higher tensile load during impact, i.e. its stiffness prevents it from absorbing any of the kinetic energy.

Further experiments have been performed to simulate rail cars of different lengths which would represent different volumes of compressed air within the brake pipe during hose separations. The air pressure is set to a constant of 90psi.

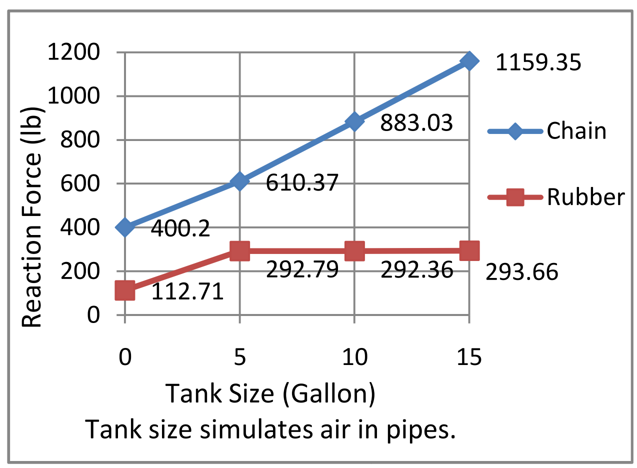

Figure 7: Reaction force created by hose separation under different air volume. Air pressure is 90psi.

Figure 7 shows that the reaction force of a rubber strap is much less affected by air volume, i.e. car length. The steel chain, however, shows a greater reaction force under higher air volume, i.e. longer cars. This high force is not only applied on the supporting strap, but to the coupler and gladhand as well. All these test results favor an elastic strap (rubber) over the rigid steel strap

3. DESIGNING AN ELASTIC STRAP

To increase the tensile strength of a rigid strap, one can either increase the strap's cross-section or use a higher strength material because strength is the only parameter available. However, to design an elastic strap requires considering both strength and elasticity. Larger cross-section and/or a higher strength material may help to increase the strap's tensile strength, but could also reduce its elasticity as well. In addition, high strength elastic materials may increase the product cost.

3.1 SET UP PERFORMANCE GOAL

Based on AAR S-4006-2008[3] new requirement, the performance goal was to have at least 10 inches of stretch under 300 lb of load (K ≤ 30) and a tensile strength 50% above the minimum or a 450 lb minimum tensile strength. Another important consideration was user friendliness, i.e. easy installation and length adjustment.

3.2 ANALYSIS OF EXISTING DESIGN

Most elastic straps have traditionally been constructed of either rubber or a polymer. Repeated tests revealed that previous strap designs have a major weakness surrounding the engagement of the metal hook with the rubber strap. Figure 7 illustrates some of the problems. The hook has two legs and both are engaged with the rubber strap at the same time. The distance between the two legs of the hook equals the distance of the adjacent holes of the rubber strap at a no load condition (the strap assembly at left of Figure 7). When loaded, a majority of the load is applied to the leg closer to the opposite end due to the great difference in elasticity of rubber and metal. The result is that both the metal hook and the hole in the rubber are over loaded. Figure 7 shows the damage to both hook and rubber.

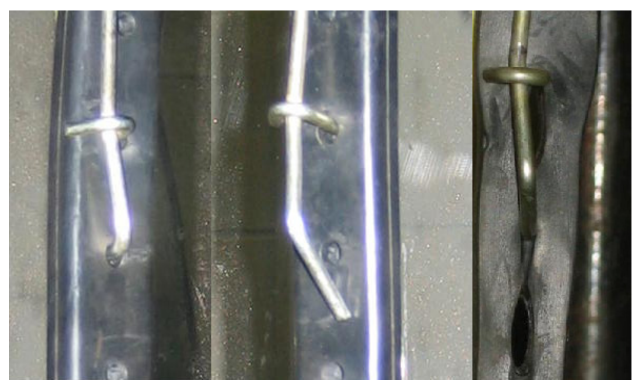

Figure 7: Previously existing rubber strap, photo shows problems of metal hook and rubber strap linkage. The strap on the left is unloaded; the middle one is after being loaded to 300 lb; the right one shows one leg came out of the rubber hole and cut into the rubber during continued loadings.

Figure 8 shows a stronger hook design but still offers no help for the rubber. During testing, the rubber always broke at the hole closer to the opposite end.

Figure 8: Previous design, failure always occurred at location closer to the opposite end

3.3 NEW DESIGN

A few simple corrections may easily increase the strap strength but may also create disadvantages. One is to increase both the rubber and hook's cross-sectional dimensions. The disadvantages of this approach would include reduced elasticity and increased difficulty for installation (stiffer hook. It must be bent with the fingers to properly engage). Another approach would be using a high strength synthetic rubber, for example, polyurethane. However, the higher cost of such rubber would greatly reduce the final product's acceptance in the industry.

After additional analysis of the weakness of the existing designs, it was decided to focus on the optimization of the metal hook-rubber strap engagement and interaction; figure 9 and 10 illustrate the final design.

This design not only greatly increases the tensile strength, but also achieves a preferred elasticity coefficient of K≤30 lb/in. In addition, there is no cost disadvantage as there are no significant changes to the metal hook or the rubber strap's dimensions.

Figure 9: Metal hook and rubber strap engagement under different load condition. Note full engagement of the inboard hook at full load (right hand photo)

Figure 10: Side view of duel-leg metal hook engaged with rubber strap under medium load condition

The main feature of this new design is that the distance between the two legs of the hook is wider than the distance between the two adjacent holes of the rubber strap. (The adjacent hole distance is regulated by AAR S-4006-2008 [3] to no more than one inch). Unlike the previous design, in which one leg and one hole had to bear most of the load, the new design distributes the load more evenly to both legs and holes at the maximum required AAR load. Figure 9 illustrates the hook-strap engagement under three different loading conditions. During normal operation, the load only reaches a fraction of the strap's ultimate strength; most of the load would be taken by the outboard leg shown by Figure 9. This outboard leg is the stronger of the two because it approximates a "simply supported beam" as compared to most of the previous designs which were just "cantilevered". In figure 10, the leg on the right is the outboard leg and as such is a "simply supported beam". The inboard leg of the metal hook is shown in figure 9 as the bottom one and in figure 10 as the left side one. After the inboard leg starts to engage with the rubber strap during loading, most of the added load will be on this leg and further load increases on the outboard leg are negligible. To achieve a different load distribution between the two legs, we can simply change the distance between legs and holes. The current goal is to have equal load distribution at the AAR required maximum load at room temperature. This design also has the advantage of self-temperature compensation. At low temperature, while the rubber strap's elasticity coefficient becomes higher (less elastic), the tensile force applied to it by potential energy will be higher as previously discussed. However, the lower elasticity in turn leads to a higher force to engage the inboard leg; this leads to an even distribution of load with a higher force. Because this higher force will still be within the strap's strength capacity, the ultimate strength is then increased. Vice versa for a high temperature condition. Lab tests confirmed this relationship. The straps tested under -55℉ showed more than 40% higher tensile strength than the ones tested at 150℉. The prototype testing confirmed that all of the design goals were achieved.

4. CONCLUSION AND DISCUSSION

In this research and design study, it was found that the resultant force created by the impact of an end hose separation is largely dependent on the elasticity of the hose supporting strap. While a rigid metal strap may possess higher tensile strength, its ability to withstand the separation impact may not necessarily be better than elastic straps with lower tensile strength. Although the new standard [3] only requires a rigid strap to support twice the strength of a highly elastic one, both theoretical calculations and actual tests show that the real tensile force in rigid straps could be as much as five times higher than that in elastic straps. This difference is due to reacting to a force as a sudden impact versus dampening the same force with elastic absorption.

The five-fold reduction in force as achieved by a properly designed elastic strap, offers great relief to the end of car components when the hoses are uncoupled under full air. The new elastic strap, described in this paper, contains this improved performance.

5. REFERENCES

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[3] AAR Manual of Standards and Recommended practices, Section E Revision to the Standard S-4006, HOSE SUPPORTS-PERFORMANCE TESTING, Adopted: 1990, Revised: 2002, 2003, 2008. Section E [S-4006], pages 1- 4