Axial Mounting for Converters and Filters using Wiremesh Seals

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Abstract

Wiremesh seals used in diesel particulate filter mounting provide cushion to accommodate the linear tolerances of the components and also give additional axial and/or radial mounting forces. Seals are suitably selected to match the canning process and the component's design. Different types of seals are engineered to provide axial mounting support for diesel particulate filter. The axial support system is designed to give more mounting force as the a-axis crush strength of the filter element is higher (20-30 bars). The L-seal provides combination of axial and radial mounting forces for the DPF. The L-shaped radially held axial seal, with a tapered radial leg, is designed to provide the required axial force with a minimum radial force contribution. These tapered seals can be inserted on the substrate after stuffing the substrate into the shell. The Axial seal provides only axial mounting force for DPF assembly. Axial seals are engineered to fit the shell and the cone of the filter assembly. Axial support seals with different wire geometry, wire diameter and material densities are studied to optimize the compression characteristics of the seal. A cyclic compression test with in-situ heating is performed to study the effect of temperature on the mounting force of the seal. The compression characteristics are optimized to overcome the system expansion and contraction during thermal cycling due to regeneration of the diesel particulate filter.

Material	Cordierite	SiC	Aluminum Titanate
Melting Point (°C)	1460	2400	1860
Cell density (cpsi)	178	58	320
Wall thickness (mil)	12	17	12
Bulk density (g/cc)	0.45	0.71	0.74
Porosity %	50	58	51
Thermal Conductivity (W/m K)	<2	20	<2
Specific Heat (J/g °C)	1.11	1.12	0.75
Coeff. of thermal expansion CTE (µm/m °C)	0.7	4.4	0.9
Elastic modulus eMod (GPa)	4.7	13	1.45
Modulus of Rupture MOR (MPa)	2.6	8.17	1.47
Thermal Shock Parameter TSP=MOR/CTE x eMod (°C)	790	142	1127

Table 1: Diesel filter physical properties

Introduction

Conventional converter mounting, using radial mounting mats and wiremesh supports, is very effective in three-way catalytic converters and diesel oxidation converters used in light duty vehicles [1-7]. However, in some situations, the aspect ratio (diameter/length) of the diesel oxidation catalytic converter substrate is too high due to the large diameter and short length of the substrate. In such cases, the radial mounting is not sufficient to provide the required support [8]. Also due to the large size, high bulk density and high thermal expansion coefficient of the diesel particulate filter substrate, the conventional mounting system cannot provide the necessary radial mounting pressure [9-11]. Axial support along with the conventional radial support is preferred in mounting diesel particulate filters. This is possible due to the continued changes on the converter internals. Axial support flanges and metal retainer ring supports are extensively used in non-road emission control system designs. Knitted wiremesh support seals are used to protect substrate breakage due to hard surface contacts. These wiremesh seals provide axial and/or radial mounting supports also [12,13]. The shape and size of the wiremesh seals are designed to match the canning process and the converter/filter internal components.

Particulate Filter Elements

Different types of wall flow filter elements are used in diesel particulate matter control systems. Physical attributes of silicon carbide, cordierite and aluminum titanate filter elements are given in Table 1. The bulk density of the filter materials vary from 0.45 g/cc to 0.75 g/cc. The thermal properties also vary due to the

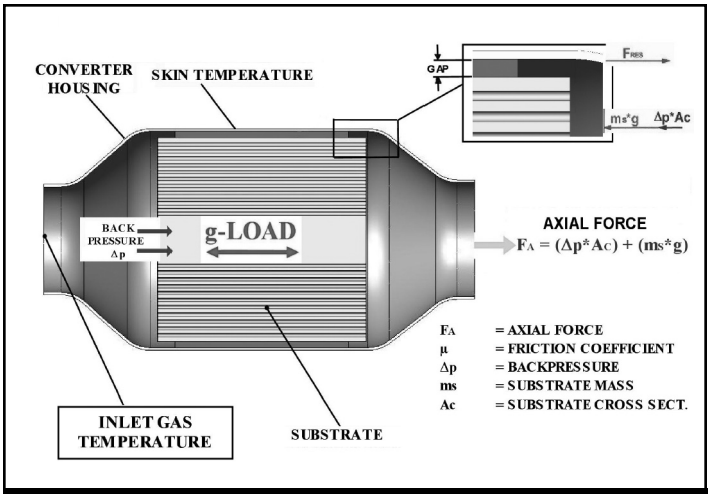

Figure 1: Force exerted on DPF

chemical composition of the materials of the filter elements. These variations in the substrates demand different mounting systems to protect the components from thermo-mechanical failures.

Mounting Force

The axial force required to hold the substrate depends on the mass of the substrate, the acceleration load, the back pressure and the substrate frontal surface area. The axial force exerted by vehicle dynamics and the substrate characteristics is calculated from the back pressure force and the inertial force.

Axial Force (F_A) = Backpressure Force (F_B) + Inertial Force (F_I)

$$F_A = (\Delta p \times A_C) + (m_s \times a)$$

The static back pressure force and the dynamic vibration force exerted on the diesel particulate filter during the vehicle operation is illustrated in Figure 1.

The minimum force required to mount the filter system is calculated for a given size of different filter elements. The necessary compensating force to accommodate the road load, engine load and the thermo-mechanical system deformations and degradations is not included in the axial force given in Table 2.

Substrate Material	Cordierite	SiC	Aluminum Titanate
Substrate dimension (inch)	Ø15"x15"	Ø15"x15"	Ø15"x15"
Substrate weight (kg)	26	41	43
Back pressure (kPa)	45	45	45
Acceleration g-forces (g)	15	15	15
Axial force (kN)	8.96	11.16	11.46

Table 2: Axial force exerted on the substrate

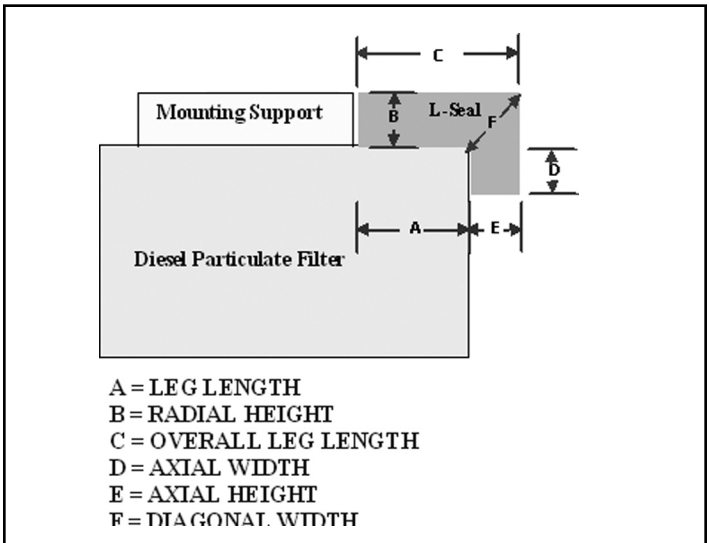

Figure 2: L-Seal dimensions

The support system should provide more than the needed mounting force axially, radially or by combination of both to accommodate the support system deterioration due to can deformation and loss of mounting system weight (vibration and erosion). The residual force given by the seal at the maximum and minimum gaps are determined by cyclic compression test. The seal is selected based on the residual compression force.

Axial and Radial Support Seal

The L-seal is an "L" shaped edge protector made up of wiremesh material providing radial and axial support to the substrate. The design dimension of L-seal is given in Figure 2. L-seal axial and radial mounting forces are derived from the compression curves. The total mounting force provided by the L-seal is calculated from its radial force (F_r) and axial force (F_a) contributions as described below.

$$F_T = F_a + F_r * \mu$$

The L-seal is mounted on the edge of the substrate around the lateral surface as shown in Figure 3. The axial force contributions are more than the radial force due to the frictional property of the system. The L-seal is used in filter mounting using tourniquet and loose stuffing and sizing processes.

Radially Held AXIAL Support Seal

Radially-held axial seal dimensions are given in Figure 4. This seal can be inserted on the substrate after the substrate is stuffed. This seal is preferred in DPF mounted by the hard stuffing process. Figure 4 shows the dimensions of the seal with tapered radial leg. The figure shows the uncompressed stage of the seal. The seal will be held tight when the gap is closed and the shell is assembled. The radial leg is designed to give only a radial holding effect and not any radial forces to the mounting system.

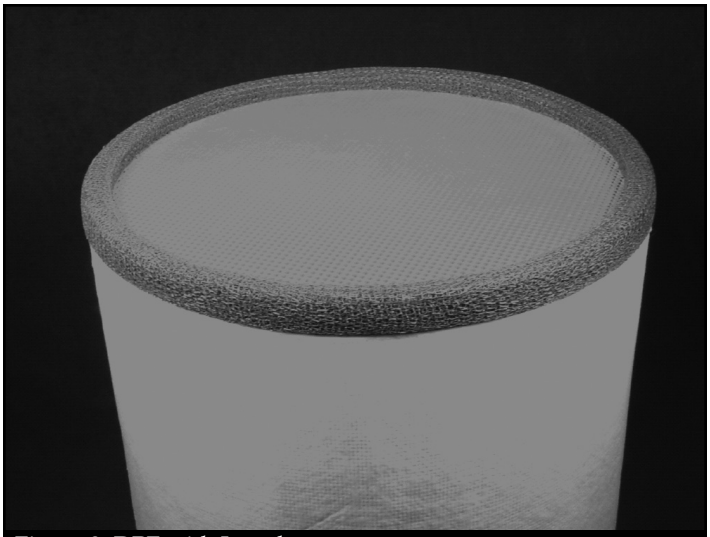

Figure 3: DPF with L-seal

Axial Support Seal

Axial support seals are designed to give only an axial mounting force to the filter element. The typical axial support seal dimensions are given in Figure 5.

The axial seal can be mounted in several ways depending on the geometry and location of the axial supporting component in the assembly. Figures 6 -10 show different ways of mounting axial support seals in the filter assembly. The retainer rings and the cone designs are being used to hold the axial support seal. The seal can be welded on the face of the supporting component also.

A typical example of the axial seal mounted on the diesel particulate filter is shown in Figure 11.

Seal Design Criteria

The seal design process starts with the customer specific inputs such as vehicle information, engine characteristics, exhaust gas mass flow rate and temperature histogram. Axial and radial forces, compression behavior and spring back curves are modeled. The design optimization criteria and material selection are based on the customer defined targets such as radial and axial gap, initial

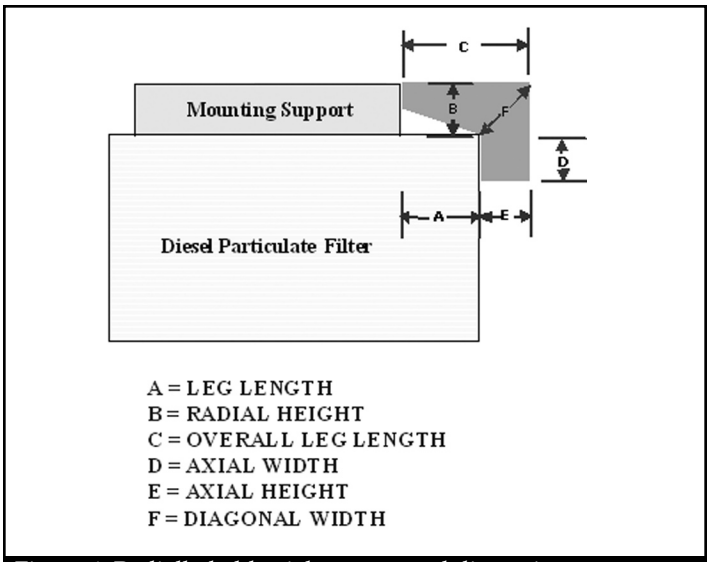

Figure 4: Radially held axial support seal dimensions

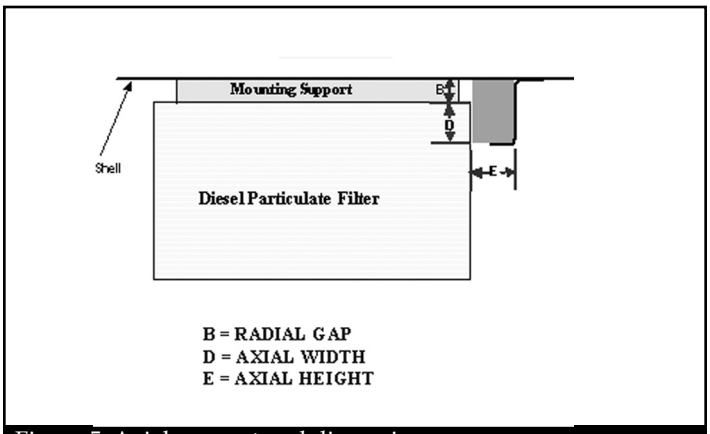

Figure 5: Axial support seal dimensions

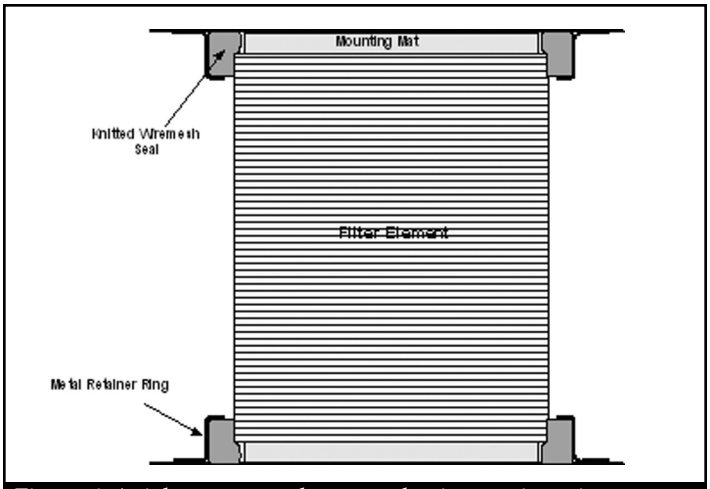

Figure 6: Axial support seal mounted using retainer ring welded outwards

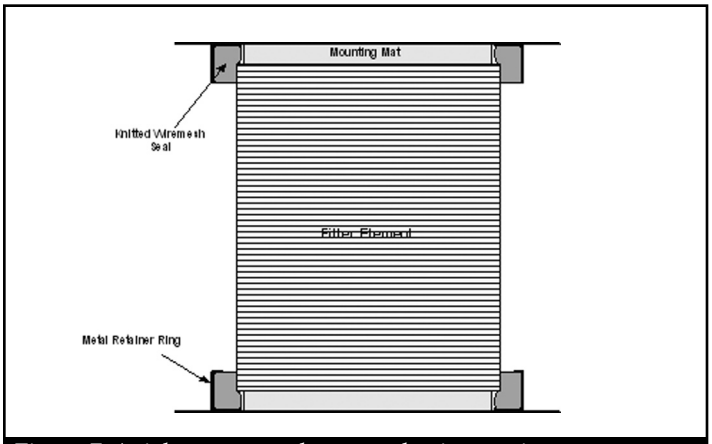

Figure 7: Axial support seal mounted using retainer ring welded inwards

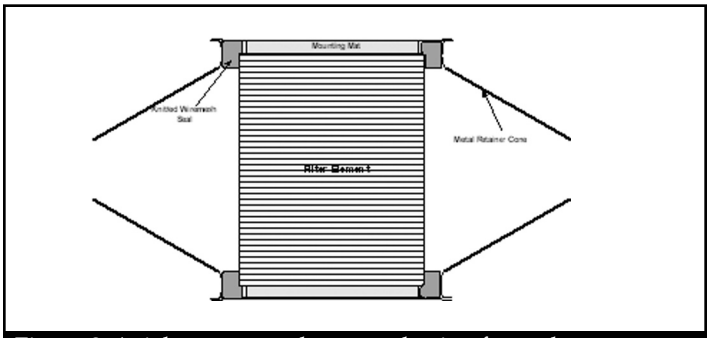

Figure 8: Axial support seal mounted using formed cone

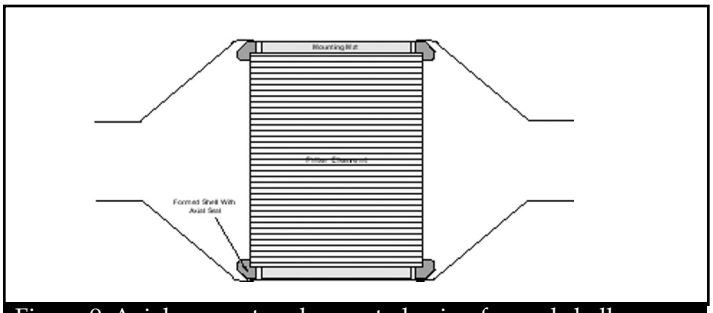

Figure 9: Axial support seal mounted using formed shell

and residual compression forces, durability, weight and other seal dimensions. The prototypes produced and validated using the optimized soft-tools, give the validation comfort level. Verification of Design of Experiment (DoE) and production validation (PV) tests of the product produced from the production hard-tool satisfies the requirements. The seal weight selection process is given in Figure 12. Parameters such as diameter of the seal, weight of the material, material thickness and mesh type are used to optimize the compression characteristics of the seal.

Seal Material Selection Criteria

The seal material is selected based on the axial and radial compression characteristics required for the mounting system. Seal overall length, leg length, radial gap, axial height and axial width are optimized. Variables such as wire material, wire geometry, wire density, wiremesh courses per inch, needle count, and number of strands, wiremesh temper, wiremesh surface profile and surface friction characteristics are changed to get the necessary axial and radial compression spring rates. Table 3 illustrates the physical and chemical characteristics of different seal materials.

The seal materials are chosen to accommodate the continuous operation temperature, thermal spike and the system expansion and contraction characteristics.

Commonly used seal materials are Stainless Steel 304, 310S, A286 and the combination of these. A286 with high ultimate tensile strength, yield strength and low coefficient of thermal expansion provides high compression force compared to 310S. A combination of A286 and 310S wiremesh is preferentially used in applications where higher compression spring rates are needed, as A286 upon heat treatment, hardened by precipitation, yields about 20 % higher compression. Corrosion resistance and oxidation resistances are typical for this material to be used in exhaust system.

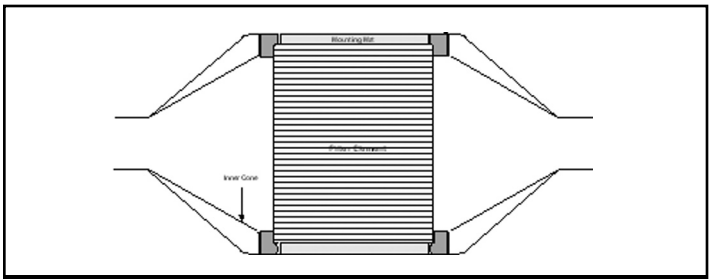

Figure 10: Axial support seal mounted using formed inner cone

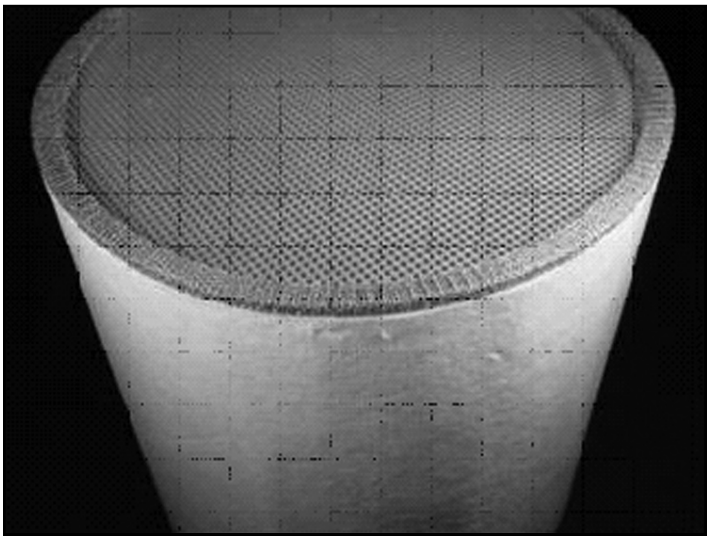
Figure 11: DPF with axial seal

Material	304	310S	A 286
Chemical Composition			
Chromium %	18 - 20	24 - 26	15
Aluminum %	0	0	0.20
Iron %	68 - 74	48 - 55	56 - 59
Nickel %	8 - 12	19 -22	26
Carbon %	0.08	0.08	0.08 max
Physical Characteristics			
Melting Point (°C)	1400	1400	1400
Maximum operating temperature(°C)	900	1100	982
Density (g/cm³)	8.03	8	7.91
Electric resistivity (µohm-m at 20 °C)	0.72	0.72	0.91
Coeff. Of thermal expansion (µm/m K)	17	15.9	9.17
Thermal Conductivity (W/m K)	16.2	14.2	17.8
Specific Heat (kJ/kg K)	0.50	0.5	0.42
Mechanical Properties			
Ultimate Tensile Strength (MPa)	621	515	760
Yield Strength (MPa)	290	205	350
Elongation at rupture (%)	55	40	40

Table 3: Properties of seal materials

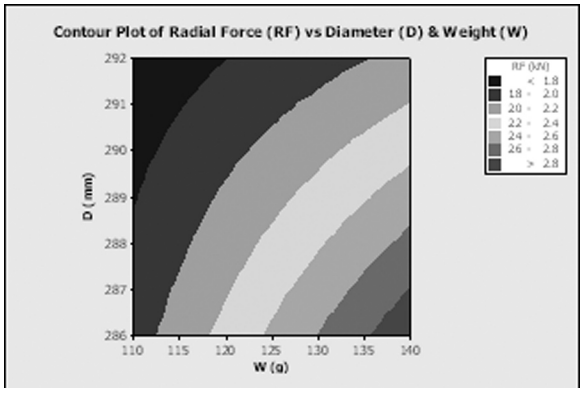

Figure 12: Variation of force as a function of seal diameter

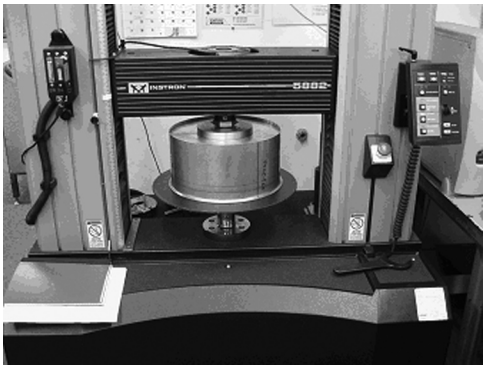

Figure 13: Axial compression test fixture

Compression Characteristics

The axial and radial compression characteristics of the seals are measured using computer controlled Instron 5882 with Blue Hill software. The seal is assembled on a substrate with a shell around to radially capture as it is in the filter system assembly and the compression is measured (Figure 13).

Compression of the wiremesh produces a force that is dependent on the type of material, seal density, wiremesh strand, wiremesh surface profile (flat or round), wiremesh surface characteristics, wiremesh temper, thermal impacts and geometries.

In order to evaluate the compression characteristics of the seal during the vehicle dynamics, the seal is mounted in between the heated platen and the cyclic compression measured as shown in Figure 14.

A typical set of axial compression curves is shown in Figure 15. The compression curves show the variation of force as a function of closing gap. The seal to seal variation of the compression curves given in Figure 15 is used to set up the filter canning process, either to close to the force or to the required gap.

The compression characteristics are changed by different types of knitted wiremesh designs. The variation of the compression force as a function of gap for two different designs of the seal is given in Figure 16. Not only the residual force but also the springback characteristics are changed by the geometry and configuration of the knitted wiremesh.

Seal Density

Axial seals with different material densities were studied. It was found that the compression force increases as weight increases. Figure 17 illustrates the axial compression pressure as a function of seal weight.

Results of the cyclic compression test performed on seals with different material densities are shown in Figure 18.

The initial and the residual compression forces are changed by material densities as expected.

Seal Material

Compression characteristics are changed as the hardness of the material change. Some materials harden during mechanical drawing and some on heat treatment, due to precipitation. Upon heat treatment, materials like A286 precipitate yielding higher compression characteristics. 310S does not show a similar change in compression characteristics on heat treatment. However, a combination of A286 and 310S shows a controlled change of spring rate. Figure 19 shows the variation of spring rates for A286 and A286/310S combination.

The radial pressure is measured before and after heat treatment on A286 half hard (HH) and 310S flat wires and their combinations. The cold compression force can be varied between 1.1 to 2.2 MPa. Substantial increase is found on heating at 650 ˚C for 15 minutes (1.8 - 3.8 MPa). L-seals were made of pre-heat treated wire. Fur-

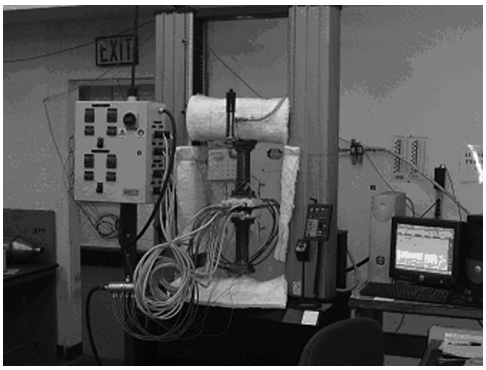

Figure 14: Compression test with in-situ heating

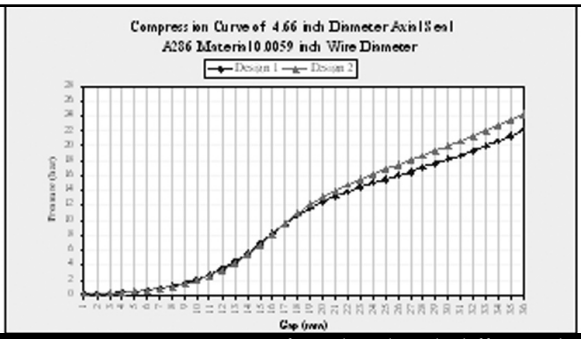

Figure 16: Compression curve of axial seal with different designs (A286 material)

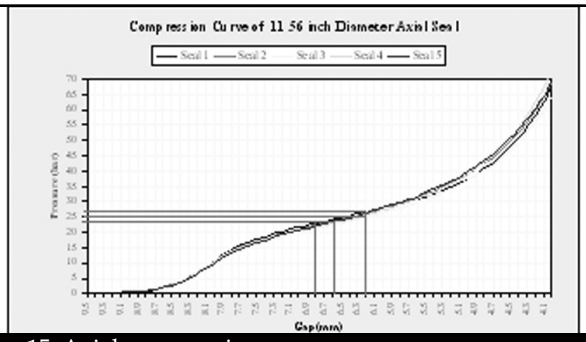

Figure 15: Axial compression curves

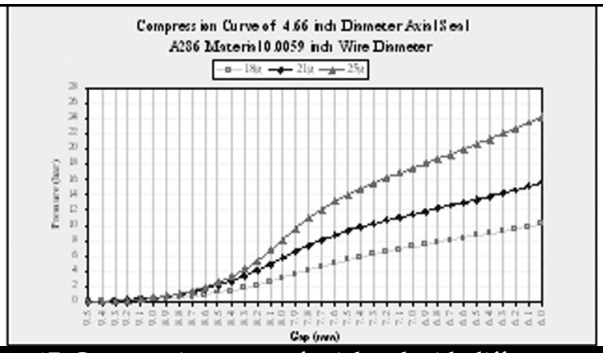

Figure 17: Compression curve of axial seal with different densities (A286 material).

ther heat treatment of these L-seals at different temperatures did not show any thermal loss. This clearly shows that the precipitation of A286 is complete.

Wire Diameter

The compression characteristics of the axial seal using different wire diameter were studied. The results are shown in Figure 20.

The compression force increases as the diameter of the wire changes within a range. Usually wire diameter between 0.15 mm to 0.36 mm is used for seal applications.

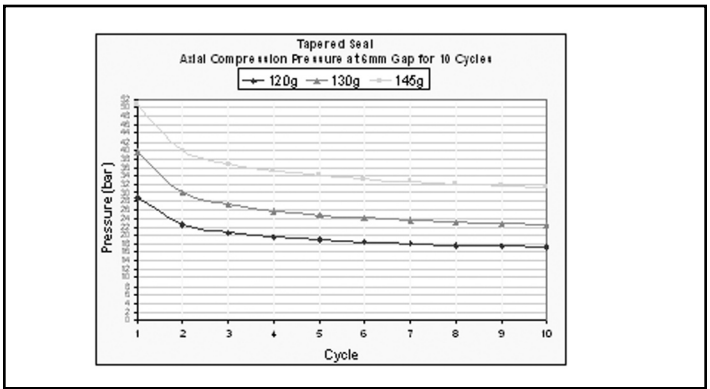

Figure 18: Cyclic axial compression curve of tapered seal with different densities

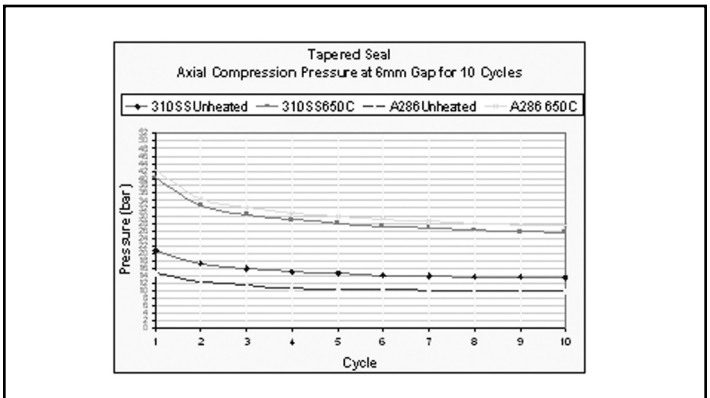

Figure 19: Cyclic axial compression curve of tapered seal for different materials

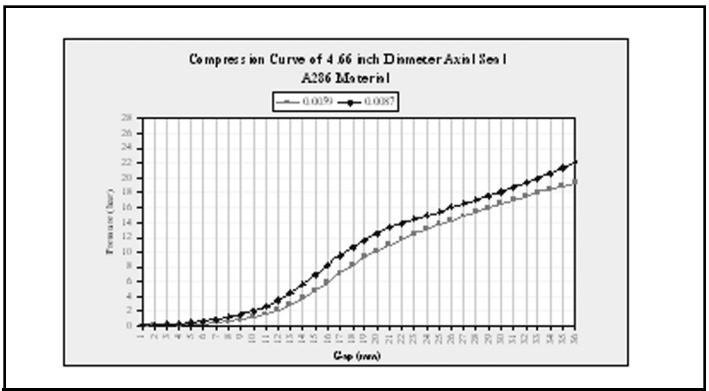

Figure 20: Compression curve of axial seal with different wire diameters (A286 material)

Axial Free Height

The compression characteristics also change as the free height of the seal changes. Two representative seals with different axial free height are compressed into the required gap. As expected the compression force exponent changed (Figure 21). This is very critical for closing the filter assembly to avoid damage to the filter element plugs.

The multiple cycle compression studied using the variation of gap gives a good idea about how the springback characteristics will protect the assembly during the expansion and contraction of the gap in the system. The thermal and mechanical spring back on the seal is a critical factor in the design of the seal (Figure 22). The 100-cycle cold compression forces are measured to understand the springback coefficient and to determine the residual force. The seal is holding the same spring characteristic at different closing gaps retaining the elastic function. The residual force at the maximum and minimum gaps is shown in Figure 22.

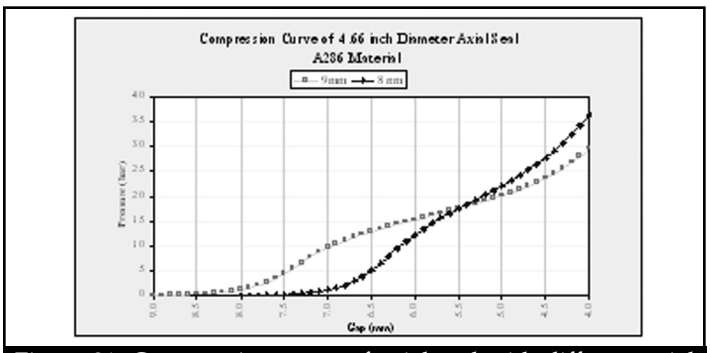

Figure 21: Compression curve of axial seal with different axial height (A286 material)

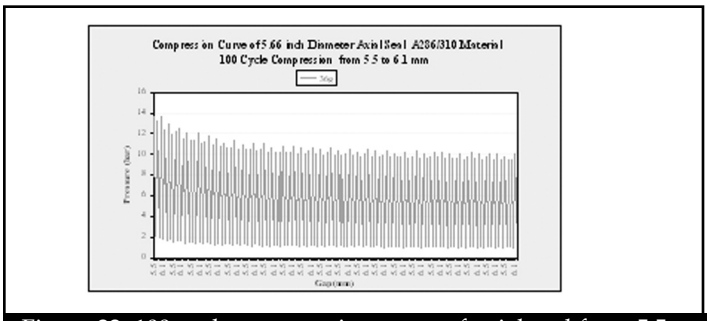

Figure 22: 100 cycle compression curve of axial seal from 5.5 to 6.1 mm gap (A286/310 material)

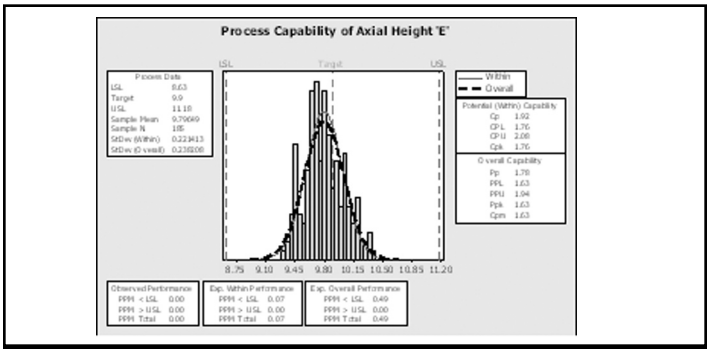

Figure 23: Process capability of the seal manufacturing

Manufacturing Process

The seal manufacturing process capability has been established. An example of the process compliance is illustrated in Figure 23.

Conclusions

Knitted wiremesh seals used for mounting support in diesel particulate filter provide a cushion to accommodate the linear tolerances of the components and additional axial and or radial mounting forces.

Seals are designed to accommodate the canning process. Different types of seals are designed to provide axial support for the system.

An L-seal provides combination of axial and radial mounting forces for the DPF

An L-shaped radially held axial seal provides axial force with minimum radial force. A tapered radial leg seal is inserted on the substrate after stuffing the substrate into the shell.

The axial seal provides only axial mounting forces for DPF assembly. Axial seals are engineered to fit the shell and the cone of the filter assembly.

Axial and radial mounting forces are altered by material selection, surface characteristics, heat treatment and wire geometry.

The compression characteristics of A286 tremendously increase (>20%) during heat treatment as precipitation and hardening occur.

Within the elastic limit of the seal, the relative loss of force during cyclic compression as a function of closing gap is constant.

Acknowledgements

The authors acknowledge Steven Buckler and Jeff Buckler of ACS Industries Inc. for their support.

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BIOGRAPHY

Dr. Sivanandi Rajadurai is the Vice President of ACS Industries Inc. In his role, he directs exhaust product development efforts. Dr. Sivanandi Rajadurai has been involved in Catalyst and Exhaust Products Development for the last 30 years. Dr. Sivanandi Rajadurai received his Ph.D. (1979) in Physical Chemistry (Heterogeneous Catalysis) from the Indian Institute of Technology, Chennai. Rajadurai has a mix of academic and industrial experience. Dr. Rajadurai worked as Assistant Professor of Chemistry at Loyola College, Chennai from 1080-85 and Research Associate Professor at University of Notre Dame from 1985-90. Rajadurai worked as a Research Leader and Director of Research at Cummins Engine Company and Molecular Technology Corporation (1990-96), Director of Advanced Development at Tenneco Automotive (1996-02) and Director of Emissions Systems at ArvinMeritor Inc.(2002-2004) and now as Vice President of ACS Industries.

Dr.Rajadurai is a Fellow of the Society of Automotive Engineers. He is a life member of the North American Catalysis Society, North American Photo Chemical Society, Instrumental Society of India, Bangladesh Chemical Society and Indian Chemical Society. He was the UNESCO representative of India on low-cost analytical studies (1983-85). He was awarded the Tenneco Innovation Award in 1998, 1999 for developing computer-aided tools for converter design and for validating low noble metal catalytic converter. He received the General Manager's Leadership Award (1998) and also the 2000 Vision Award for developing strategies for cleaner, quieter, and safer transportation. Dr.Rajadurai is a panelist of the Automotive R&D Scientists and Technologists of Indian Origin, New Delhi 2004. and Member of the Core-Group Automotive Research (CAR), India.