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An Investigation Into the Effect of Gasket Compressibility on Load Distribution in a Bolted Joint

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Abstract

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AN INVESTIGATION INTO THE EFFECT OF GASKET COMPRESSIBILITY ON LOAD DISTRIBUTION IN A BOLTED JOINT

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Chapter 1

INTRODUCTION

Background of the Problem

Since the early beginning of the Industrial Revolution, man has created various products that require the joining of two flanges in such a manner as to prevent either the escape of fluids or gases from within the assembly, or to make the joint impervious to outside contaminants. Usually the joints utilize a system of fasteners, very often bolts or capscrews, to accomplish the actual joining of the flanges, and to prevent the escape or entrance of gases or fluids, a gasket is usually placed between them.

This type of flange, bolt and gasket concept is fairly common in several of the products we use everyday. Automobile engines and drivetrains contain numerous joints of this type as well as other consumer products such as refrigerators, lawn care equipment, washing machines, power tools etc. It is important in all of these as well as other applications that adequate sealing of the flange surface is available to prevent escape of internal fluids such as lubricating oils and coolants, and to prevent infusion of outside contaminants. This seal is important to provide adequate product life and customer satisfaction.

To accomplish an acceptable seal on a flanged assembly requires correct interaction between the flange itself and the gasket material selected for use.

Statement of Problem

The problem of this study was to investigate what effects gasket materials compressibility had on clamp load distribution in a bolted joint.

Statement of Purpose

The purpose of this study was to understand what the effects of various gasketing materials compression characteristics had on flange loading in bolted joints. In effect, it was determined whether the substitution of alternative gasket materials could enhance the clamp load distribution on bolted joints.

This information was useful to the researcher as it contributed to the limited amount of information available on this particular subject. It contributed to the professions knowledge also, as it allowed them to utilize the study's results and apply them to their particular situations. Society also benefitted, as it allowed industry to understand gasketing more thoroughly, and provide society with improved products.

Statement of Need

During the production lifetime of a product, it may be determined that revisions or substitutions are required that differ from the original design. These revisions could be based on availability of materials, customer dissatisfaction with the present design, or discovery of an inadequate design in the production environment.

In the area of gasketed joints, these factors are a reality, and in an effort to ultimately satisfy customer demands, cost, and production restrictions, the most cost-effective revisions need to be considered.

The need for this study was based on the following factors:

1. Due to the decreasing availability of gasket materials containing asbestos or restricted chemicals, substitutions are necessary to maintain current production requirements. These substitutions of different gasket materials with different compressibility characteristics occasionally cause leakage in a previously good joint. The reason for this phenomenon needs to be understood to allow the responsible party to make the correct substitution of material in the production product. Therefore, it became necessary to observe what effect these material differences may have on the flange load distribution in existing joint configurations.

Roy L. Whitaker of Colt Industries says, "Non-asbestos gasket development has renewed the need for additional testing utilizing typical specifications" (Whitaker 1985 p.38). In addition Mark A. Moser in a recent article from Water Engineering and Management March 1989 states, "Frequently chemical anti-stick coatings (such as silicone) latex-coating, or beads are applied to the gasket. Sometimes these increased the materials propensity to crush at lower than expected results" (Moser 1989 p.36). As illustrated, the need for further understanding of the results of material substitutions is required.

2. It is not uncommon to discover in production, that the design of a gasketed joint is not acceptable and a revision may be necessary. Due to the high cost of total redesign of a flanged joint and subsequent prototype testing and revised tooling, it would be advisable to try substituting alternative gasket materials to correct the problem. This substitution could be very quick, cost-effective and successful if a thorough understanding of material characteristics effects could be understood.

Jess W. Oren of Armstrong World Industries, Inc. states,"The compression characteristics of a gasket material must be known so that by proper loading (flange pressure or gasket compression stress) the required sealing pressure can be created and maintained" (Oren 1981 p.2). Robert J. Finkelston of SPS Technologies says that one of the major problems with cylinder head gasketing is "Distribution of gasket clamping pressure." He also states that efforts have been made through the years such as "Better understanding of the interaction between the elasticity of the bolts, cylinder head and block components, and the stiffness properties of the gasket" (Finkelston 1981 p.2). In addition he states, "The gasket stiffness is non-linear and creates another source of joint variability" (Finkelston 1981 p.3).

The literature indicates that although a better understanding of joint characteristics is being developed, the need for more information on a gasket materials effect on load distribution is necessary.

3. A customer's quality expectations are constantly changing. What may have been acceptable before, may no longer be tolerated. Again, due to the high costs associated with redesign or retooling, revised gasketing materials may be substituted to reduce customer complaints. If a thorough understanding of the effects of material change cannot be determined, the wrong material could ultimately be chosen. This could obviously result in a worse situation than before, and increase customer dissatisfaction.

Research Questions

The questions that were to be answered in the research study consisted of the following:

1. What effect does gasket material compressibility have on the distribution of clamp load in a bolted joint?

2. Can substitution of alternative gasket materials enhance, hinder, or have no affect on the clamp load distribution in a bolted joint?

Assumptions

This study has the following assumptions:

1. That sources utilized in the review of literature followed acceptable industry standards when evaluating gasket materials and their affect on clamp loads.

2. That similar results on clamp load distribution could be achieved when utilizing other flange designs with alternative materials.

3. That supplier load compression curve values of their gasket material conform to industry standards.

4. That gasket material variation from production lot to lot will not vary significantly to affect a sample test.

5. That the use of pressure sensitive "Fuji Film" to measure clamp load distribution is an accurate, repeatable method.

Limitations

This study was conducted in view of the following limitations:

1. The majority of the research would consist of literature review and information gathering.

2. Actual experimentation with information from the literature would consist of only four tests due to time and budget constraints.

3. That evaluation of the "Fuji Film" results would be completed by a recognized gasket vendor. Availability of required equipment to analyze the films is limited and very costly.

4. That the flanges used for test were current production John Deere transmissions valve assemblies.

Definition of Terms

Fuji Film: Fuji Prescale Film - developed by Fuji Color Film Technologies and they are the sole manufacturer of this type of product. Fuji Film is a pressure sensitive sheet that they will measure ultimate pressure developed in a flanged joint, and will also show load distribution.

Summary and Outline of Succeeding Chapters

A better understanding of gasket material compressibility and its effect on clamp load distribution in a bolted joint is important to future designs and applications. A current application of this information will be useful in correcting leakage problem assemblies currently in production without creating excessive costs associated with redesign. This study helped gain a better understanding of how these factors interact, and enabled responsible persons to use this information on decisions regarding possible gasket material recommendations.

What follows in Chapter II is a Review of Related Literature. This review, summarizes several articles on gasketing, and gasket material and the interrelated effects of gasket material changes as it effects clamp load.

Chapter III describes the Methodology used to research, design and complete the entire study and the steps for completion.

Chapter IV includes Presentation and Analysis of Data section that reports on the data from the completed research and explains its importance. Chapter IV also includes a Conclusions section that answers the research questions, and a Recommendations section that includes recommendations as a result of the study.

References will follow Chapter IV, and this will be a complete listing of all references utilized in the pursuit of this research study.

Chapter 2
REVIEW OF LITERATURE

The world of gasketing technology has been around for a considerable amount of time. The study of the interaction of gasketing materials and flanges and their affect on sealability has been a continuous process. Increasing pressure for higher quality leak free products and the reduction of available materials has increased the development of alternative materials.

One of the more recent developments, was the understanding of how the substitution of a different gasketing materials in a flange can change or alter the clamping force distribution in the flange. These discoveries were due in part to new material developments, but also due to developments in the ability to measure the actual clamping forces developed in the flange. These measurement devices consisted of pressure sensitive films, computer modeling simulations, and strain gage applications to the actual mating parts. These developments have greatly enhanced the development of gasketing technology in the last few years. By applying these technological developments of material and measurement have yielded a new understanding of the interaction of gasket material and flange loading.

Recent literature on this subject has revealed that very little development has been occurring except by a few major gasket manufacturers and engineers with those companies. The majority of the information is published in SAE papers and some journal articles. Although limited, the information available was interesting and enlightening.

To begin to understand the interaction of flanges, gasket material used, and if it's affect on clamp load distribution. It was necessary to begin with a basic understanding of flanges, gaskets and how they react.

The literature available contained many definitions of flanges, but the one most appropriate was found in an Armstrong Engineering manual. In that publication, they define a flange as "a rib or rim for strength for guiding or for attachment of one object to another" (Armstrong 1990 Sec.1 p.3). A flange provides that when two pieces are attached together, that the joint is rigid and provides adequate strength. In addition to the structural requirements, a flange may also be the joint between two parts that may require the completed assembly be sealed from internal or external leakage. If this is the case, an additional means of sealing between the flanges may be necessary. This means of sealing is normally referred to as a gasket.

A gasket can be referred to as a device used to prevent the transfer of fluids across the surfaces of the flange. It can be comprised of any material or combination of materials which form a barrier to fluid transfer. Gaskets are also limited to flanges or joints that do not move relative to each other, or in effect a gasket forms a static seal. (Dynamic seals were beyond the scope of this discussion).

Gaskets are required to perform a number of requirements. It must have the ability to effectively seal the fluid, conform to any irregularities in the flange halves, and allow for easy assembly and disassembly of the flange. It must remain stable over a long period of time, and must resist creep effects that would cause a possible gasket failure.

In order for a gasket to perform the above mentioned requirements successfully, it must be exposed to adequate flange pressure when assembled. Flange pressure influences almost every factor that maintains an adequate seal. Probably <u>the</u> most important factor that influences a gasket's ability to seal properly is the flange pressure.

Apparent flange pressure was defined as "the effective compressive load per unit of gasket area expressed in pounds per square inch or in megapascals" (Armstrong 1990 Sec.2 p.1). This definition expresses the relationship of the total clamping force, developed by the fasteners (usually capscrews) divided by the total contact area of the flange. This relationship, expressed in PSI or MPA, is critical to a gasket materials success or failure.

Generally speaking, a gasket materials flange pressure requirement, are usually given in the specifications of the material. This minimum flange pressure requirement or "proficiency value" (Armstrong 1990 Sec. 6 p.1), is the flange pressure required to achieve a specified leakage rate based on industry standards. This standard is ASTM F37-89 the standard test for sealability of gasket materials.

It is vitally important, that adequate flange pressure is developed to allow the selected gasket material to perform properly. If the apparent flange pressure is determined by use of the procedure explained earlier by dividing total force by total area the selection of gasket material would be rather straight forward. Historically speaking, this was the past procedure used in the selection of a gasket material. Unfortunately, flanges do not react according to this approach, flange pressure is not evenly distributed across the entire flange surface. Consequently, even clamping pressure is not present on the gasket material. If this uneven distribution of clamping pressure is less than the minimum values required for the gasket material, leakage will result. It becomes necessary to understand how a flange reacts when assembled, and what are the results of that reaction.

"The fact that flange deflection exists even in a "rigid flange gasketed joint" must be accepted by the machine designer "(Oren 1983 p.1). This statement indicated that designers must be aware of this phenomenon, and consider it in their design process. It also indicated a possible explanation of why current product designs are not sealing properly.

Mr. Oren (1983) also goes on to say "When a fiber polymeric gasket is compressed in a single span, two bolt flange until the required sealing stress is produced at the flange center, the pressure distribution on the flange assumes a generally parabolic shape" (p.1).

In a 1989 article from Water Engineering and Management, Mark A. Moser of Armstrong World Industries substantiates Mr. Orens claim. In that article Mr. Moser (1989) states "The greatest flange loading (and consequent gasket compression) occurs in the area immediately under the bolt or fasteners heads, and diminishes along the flange surface until the mid-point between the two adjacent fasteners"(p.38). This force diminishment can cause adverse effects on the sealing properties of the gasket material. There is a need to gain a better understanding of this phenomenon, and learn how to deal with it. It is necessary to control the amount of flange deflection so the compression throughout the gasket area is acceptable.

In order to understand why a flange bows when loaded against a gasket, an understanding of the compression characteristics of the gasket material was necessary. The relationship between percent compression and pressure of the gasket material is not a linear relationship (see appendix F). In essence, the load compression curve of a gasket material indicates a higher amount of compression with a relatively light load, and decreases rapidly requiring very high loads to increase the amount of compression. This type of load compression curve is fairly typical of the majority of todays gasketing materials.

This non-linearity of the gasket material under compression has a significant impact on the flange load distribution.

In order to better understand the relationship between the flange and gasket material, it was necessary to have a mental picture of what was happening as the flange was compressing the gasket material.

By envisioning the gasket material as a set of springs between the flange halves and pushing against them we can begin to envision this phenomenon.

By referring to Appendix G, a flange has been drawn with springs between each half. If the springs were made of steel with the same spring constant, it would be expected that an equal amount of force was exerted based on the amount of compression. This is due to the fact that in a coiled spring the spring constant follows a linear relationship that force is proportional to distance compressed.

As the bolts of the flange are tightened equally and the top flange moved down, each spring exerted the same force on the flange. For example, by lowering the flange initially by 10% and then lowering the flange an additional 10% the spring force would double for each spring, (see appendix H), as this is the nature of the elastic constant. The spring force in all the springs is relatively uniform but only slightly affected by the deflection of the flange. (Note: It was stated earlier that <u>all</u> flanges will bow). In essence the <u>initial</u> bowing of the flange would be expected, but as the flange bows, the amount of force required versus the amount of movement would stay fairly linear.

However, when a gasket material is utilized in a flange with it's non-linear compression characteristics, explained earlier, the amount of force required for additional compression would <u>increase</u> with increasing compression or movement of the flange. In effect as the flange is lowered and begins to compress the gasket material, each additional amount of compression would require considerably more force than earlier amounts of compression (see appendix I).

In Appendix I, the gasket has again been replaced by coil springs, but this time the springs will simulate the gasket materials reaction, or in other words, the springs characteristics during compression will simulate the behavior of the gasket material. During the initial compression of the gasket, very little force is exerted on the assembly, and little flange deflection occurs. This is represented by several springs all compressed equally. In this stage, the gasket material is essentially being squeezed and the gaps and pockets in the material are being removed.

In Appendix J, the fasteners are tightened exerting more force on the gasket material or in this case the springs. In this phase the flange begins to bow just like before. However, the gasket material or springs are reacting differently. Since the flange has bowed, there is more compression at the bolt areas than in the center of the flange. The increased compression in the bolt areas results in the spring rate of the gasket being more than the spring rate in the center of the span. This can be illustrated by replacing the springs in this area with heavier springs to simulate the increased amount of force being exerted in these areas.

By continuing to tighten the bolts as in Appendix K, the compression of the gasket material continues. It is now possible to replace the springs with even heavier springs at the bolt holes, and slightly heavier springs near the center. If this progression were to continue, extremely high bolt forces are necessary to move the flange, with very high forces at bolt holes and very little force in the center.

At this point, continued tightening of the bolts is ineffective to seal at the center span. In certain cases, continued tightening will bow the flange even more and extrude the gasket at the bolt areas. Mark Moser (1991) states "If the flange is drawn down into the gasket further at the bolt area, the amount of bowing of the flange can actually increase and percent of compression of the gasket at mid-span could consequently decrease"(p.7).

As illustrated so far in the literature, an understanding of gasket materials compression characteristics and how they affect the clamp load distribution of a flange is important. If a gasket material was to function properly it must have the necessary clamp force exerted in the center of the flange. This insures that the material is properly compressed to prevent leakage either through the gasket material, or across the face of the gasket. It is vitally important that these factors be considered when designing and developing a flange/gasket configuration for production. But what if a flange design is already in production and was not performing satisfactorily. Was there something that could be done?

According to Armstrong Industries, there are several methods to reduce or eliminate leakage of a gasket caused by bowing of the flange. The majority of these suggestions have to do with redesign of the flange by increasing thickness, reducing span between bolts, the width of the sealing surface etc. Although these were all excellent suggestions, all too often when dealing with current production items, redesigns can be very expensive and cause interchangeability problems with mating parts. Quite often redesign was inappropriate.

Armstrong does make another suggestion "Changing to a more compressible gasket material" (Armstrong 1990 Sec. 5 p.8). It appears that according to the literature from experts in the field that gasket material compressibility will have an effect on the clamp load distribution, and that by changing the material to a more compressible type can enhance the final load value in the joint.

It appeared from research done so far, that a clear relationship existed between clamp load distribution and gasket material compressibility. If a substitution of materials was made on a specific flange, and the effect of that change can be measured directly it would be possible to confirm what the literature is expressing.

Chapter 3
METHODOLOGY

This study was conducted using a part normally used in the current production agricultural tractor transmission that has had a history of leakage problems in production. The part used was a John Deere number RE19041 and is a rotary control valve housing cover. The gasket currently used in this application is a R92471 and is specified as being made from an Armstrong TN9004 material. The gasket materials that were tested for this application were an Armstrong TN9005, NV512 and N8090. These materials were selected to be verified against the current material due to their desirable compression characteristics.

Equipment for Experiment

The equipment used for this test consisted of the following:

1. A GSE Inc. digital torque wrench to install the capscrews used and torque to a specified value of 9 ft./ lbs.

2. An RE19041 rotary valve housing cover and mating R92471 valve housing. Note: The same parts were used for each gasket evaluation to reduce variation.

3. Pressure sensitive "Fuji Films" cut on the gasket vendors production tooling to directly match the gaskets supplied by them.

4. Pre-cut gaskets made from each of the gasket materials under scrutinization, also cut by gasket vendor with production tooling.

Procedure for Experiment

The study consisted of taking a one piece sample of each of the different gasket materials under investigation and measuring the clamp force distribution utilizing the pressure sensitive film.

The procedure for the experiment was completed as follows:

1. The test parts were procured and assembled using the pressure sensitive film between the flanges to determine clamp load without and with gasket material.

2. Both were installed and torqued to 9 ft./lbs. using the digital torque wrench.

3. Films were removed from between flanges and were returned to the gasket vendor for analysis of actual clamp load distribution. (Analysis Equipment (Densitometer) was not readily available and films had to be returned).

4. Results were tabulated.

Chapter 4

PRESENTATION AND ANALYSIS OF DATA

Information About the Data

This experiment measured the distribution of the clamp force in pounds per square inch (PSI) of pressure. Each film was read and pressure recordings were taken in specific areas of the gasket that have historically exhibited sealing problem (see appendix A-E). These readings were tabulated and an overall average of clamp load was calculated. The averages were then compared to see which material exhibited the most improvement over the production base line material. The following table illustrates the measurement results.

	BASE	ALTERNATIVES		
		1	2	3
Position	TN9004	N 8090	TN9005	NV 512
1	553	568	1280	382
2	283	284	341	0
3	923	639	1421	1280
4	341	711	652	864
5	0	284	0	382
6	1562	1422	1562	1562
Average	610	651	876	745
% Increase	NA	6.72%	43.53%	22.06%

As illustrated in the table, the average overall clamp load was 610 PSI for the production baseline material TN9004. All three of the other materials exhibited significant improvement over baseline with the TN9005 material exhibiting the highest (43.53%) improvement over the baseline.

It also demonstrated that the distribution of the clamp load had been changed from the baseline to other materials in the specific areas under study. Generally speaking, the clamp load had increased overall and was distributed across the suspect flange areas. As indicated by the table, in certain areas of little or no clamp load using the production material, alternate materials exhibited significant improvements in the ultimate clamping load generated.

Chapter 5
CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The experiments ran support the literature's claim that a gasket materials compressibility rating can directly influence the clamp load distribution in a joint. As explained and demonstrated, the use of an alternative material with different compressibility rating will alter the distribution of clamp load force in a joint.

It was also confirmed that the substitution of materials with higher compressibility ratings can enhance the load distribution in a flange.

Recommendations

The following recommendations should be considered when dealing with gasketed flanges.

1. If a present production joint is not performing satisfactorily, consider changing to a more compressible material.
2. If a substitution of materials is necessary due to an availability problem, always consult the suppliers compressibility data to try and match as close as possible.

3. When designing gasketed flanges, always consider the compression characteristics of the material.

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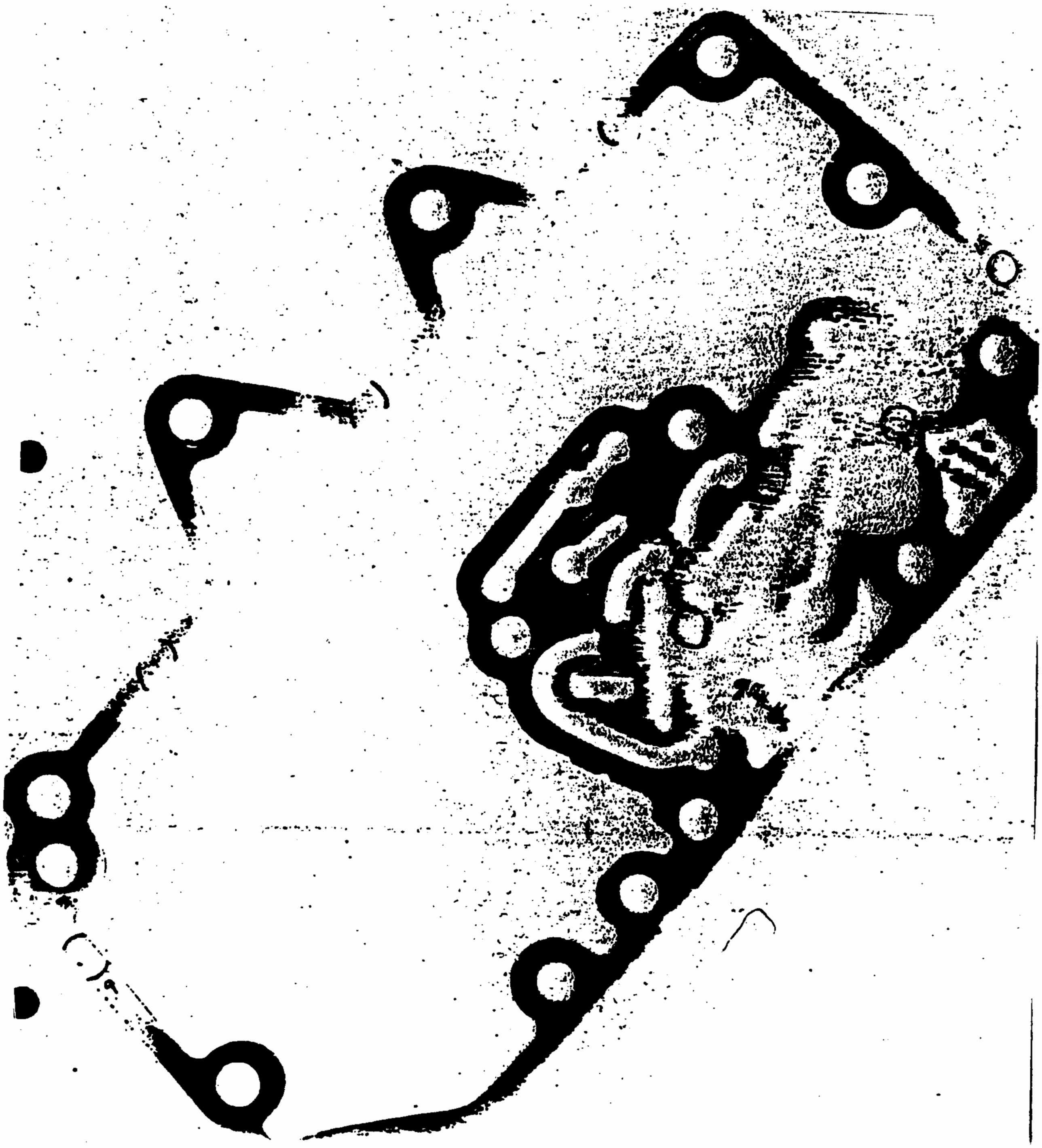
APPENDIX A

NO GASKET 9 FT/LBS TORQUE

Appendix A

No Gasket 9 Ft/Lbs Torque

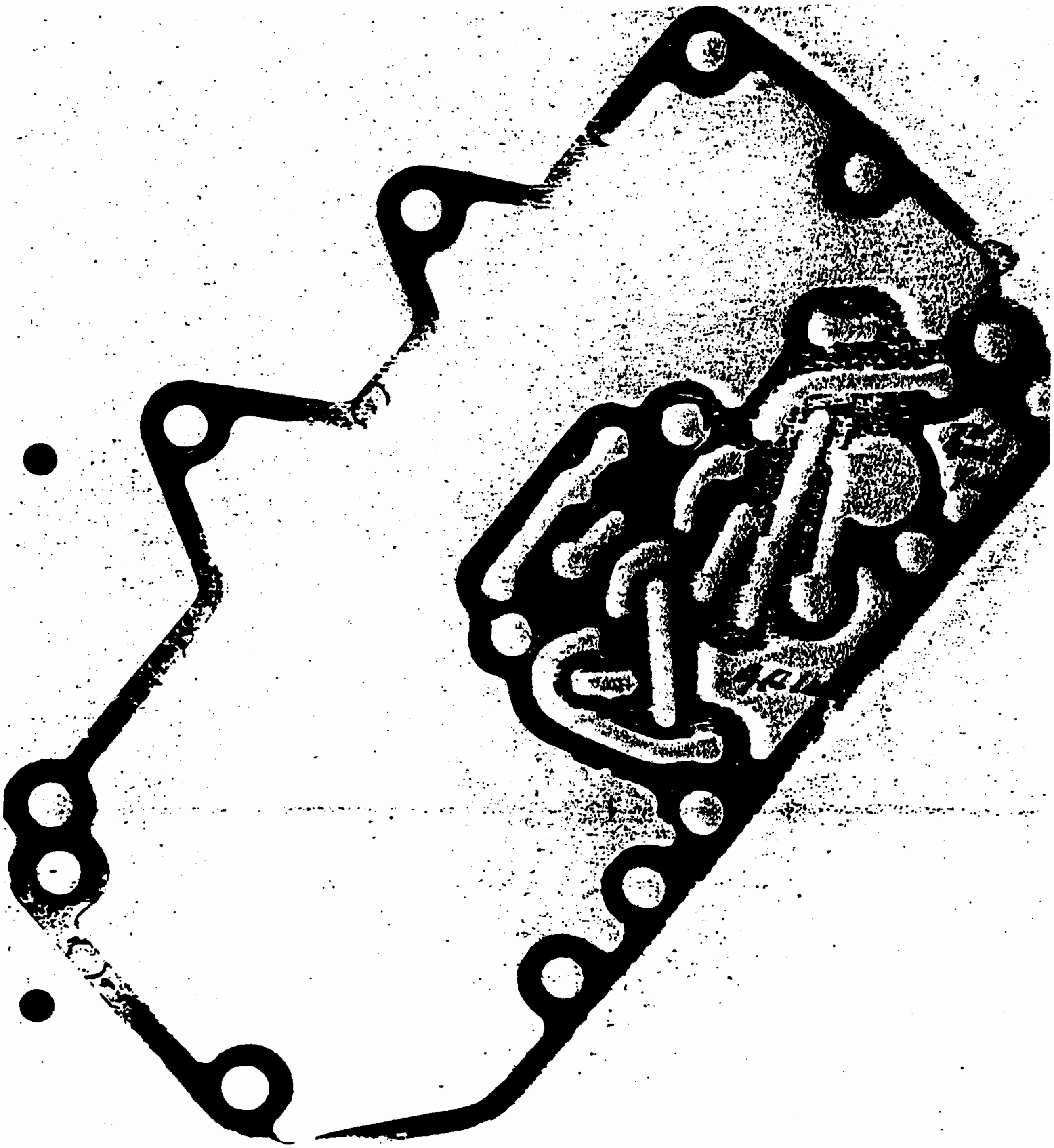


APPENDIX B

TN 9004 9 FT/LBS TORQUE

Appendix B

TN 9004 9 Ft/Lbs Torque

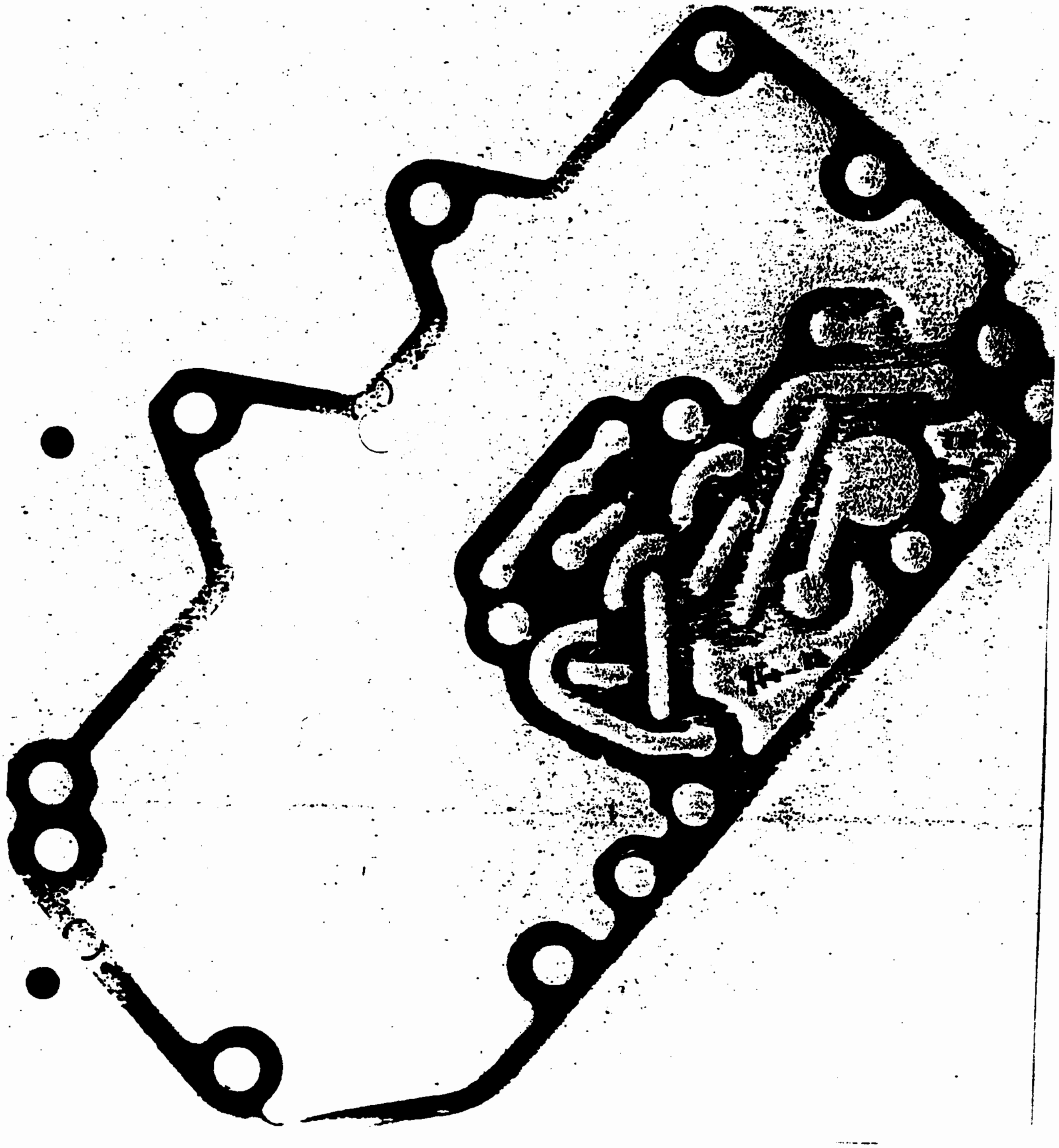


APPENDIX C

TN 9005 9 FT/LBS TORQUE

Appendix C

TN 9005 9 Ft/Lbs Torque

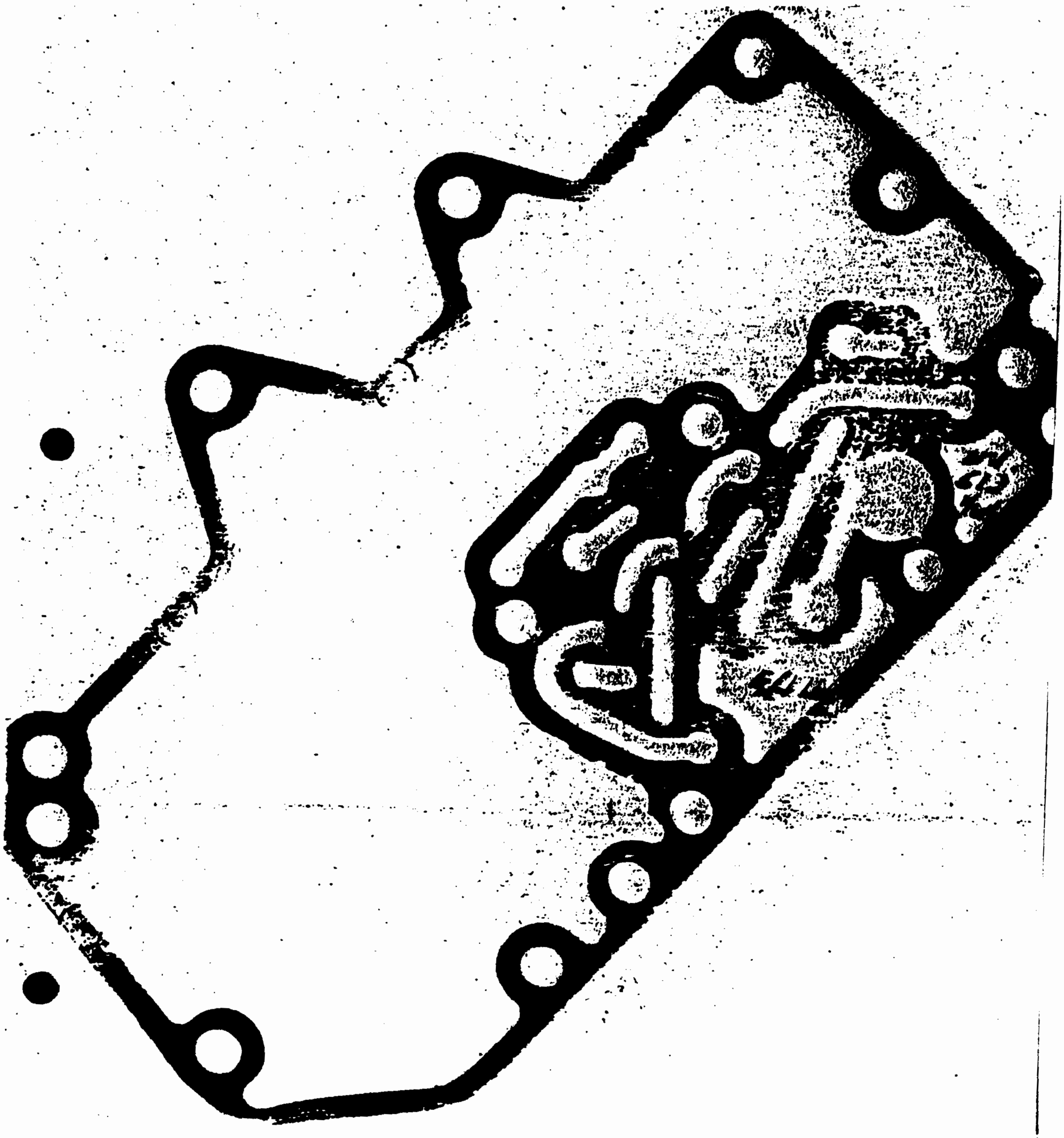


APPENDIX D

NV 512 9 FT/LBS TORQUE

Appendix D

NV 512 9 Ft/Lbs Torque

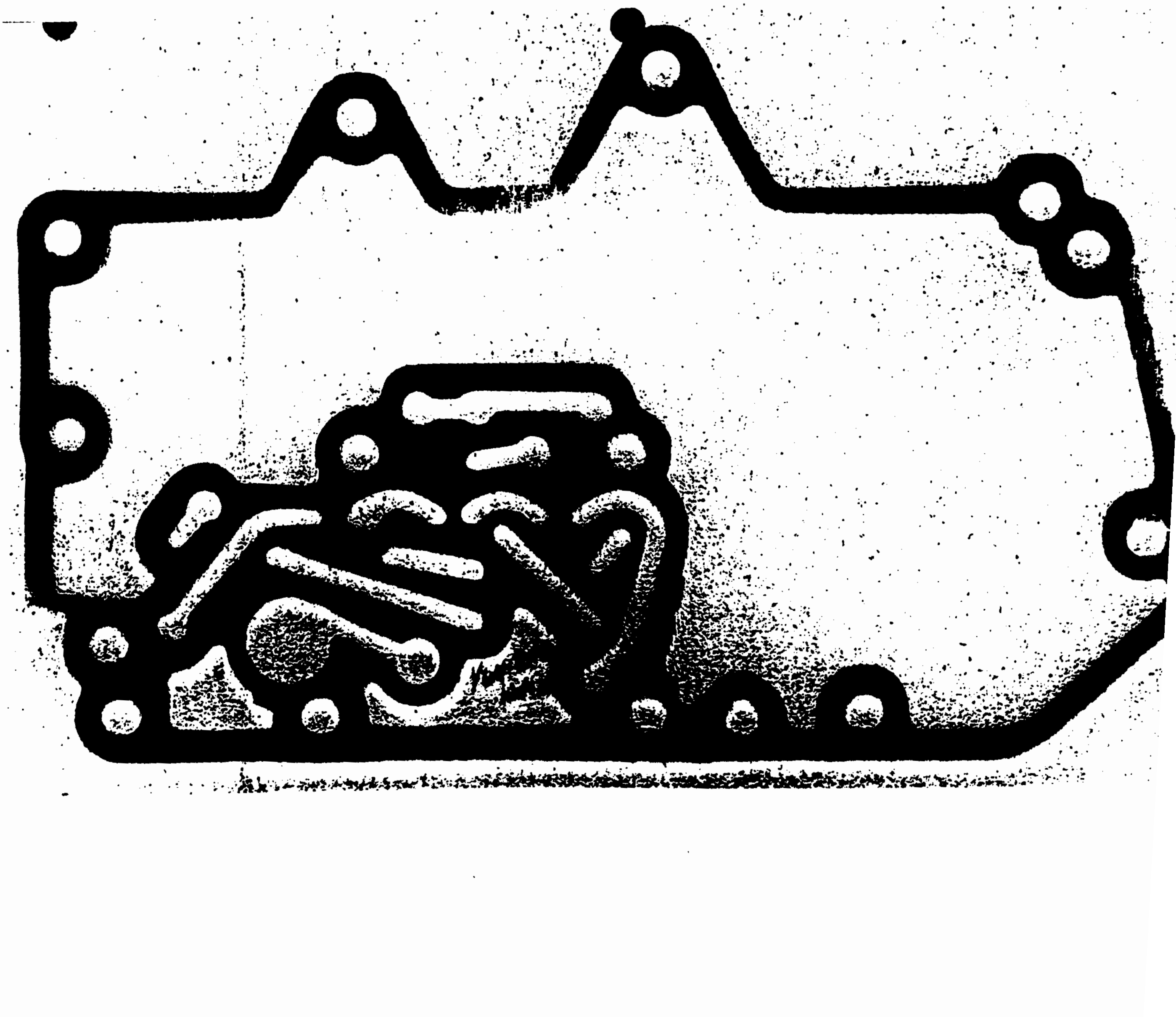


APPENDIX E

N 8090 9 FT/LBS TORQUE

Appendix E

N 8090 9 Ft/Lbs Torque

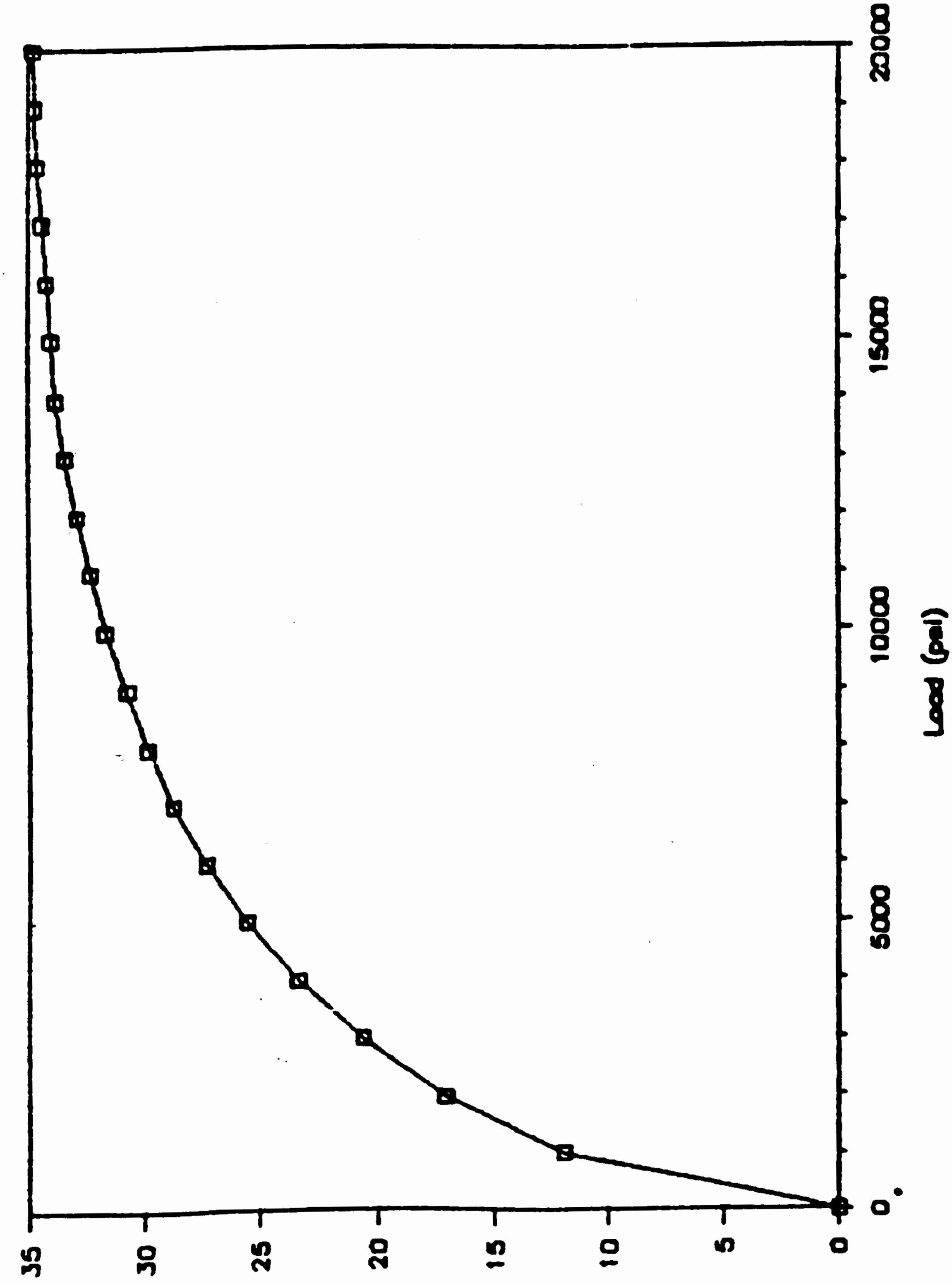


APPENDIX F

TYPICAL GASKET LOAD COMPRESSION CURVE

Appendix F

Typical Gasket Load Compression Curve

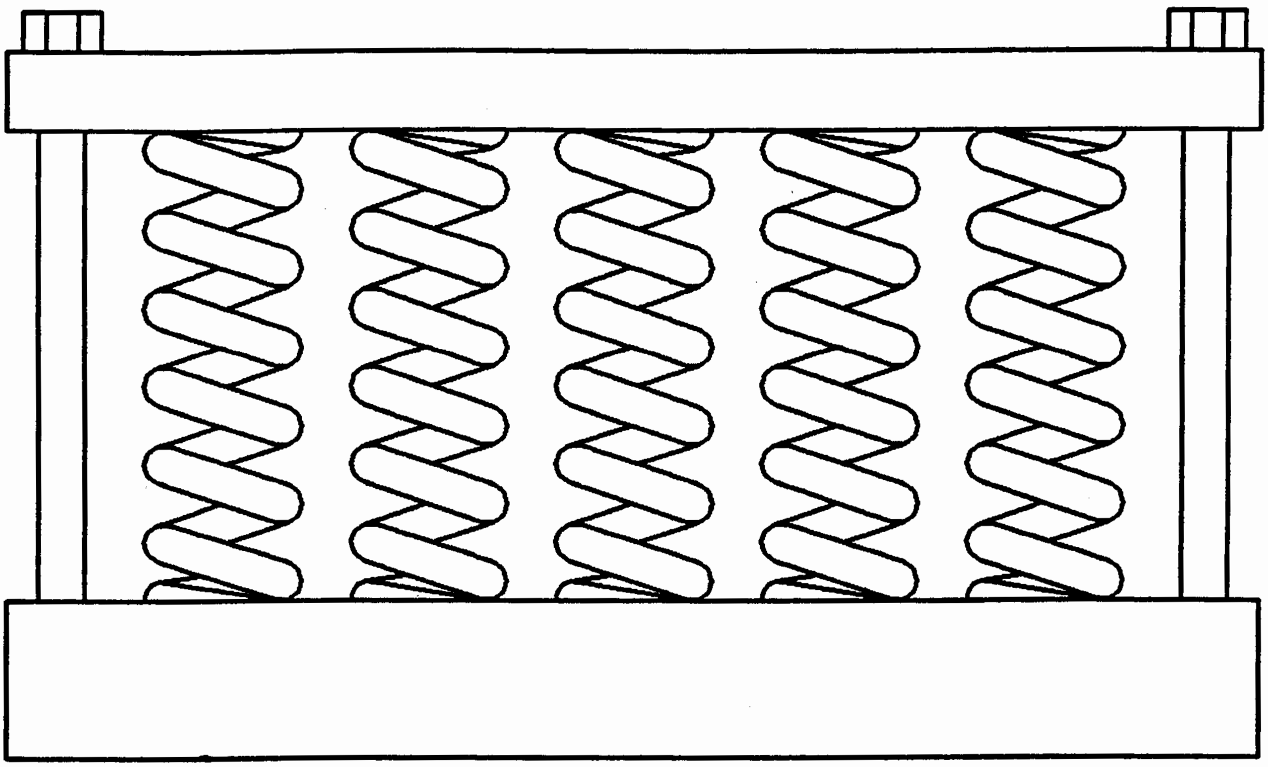


APPENDIX G

STEEL SPRINGS LINEAR COMPRESSION RATE

Appendix G

Steel Springs Linear Compression Rate

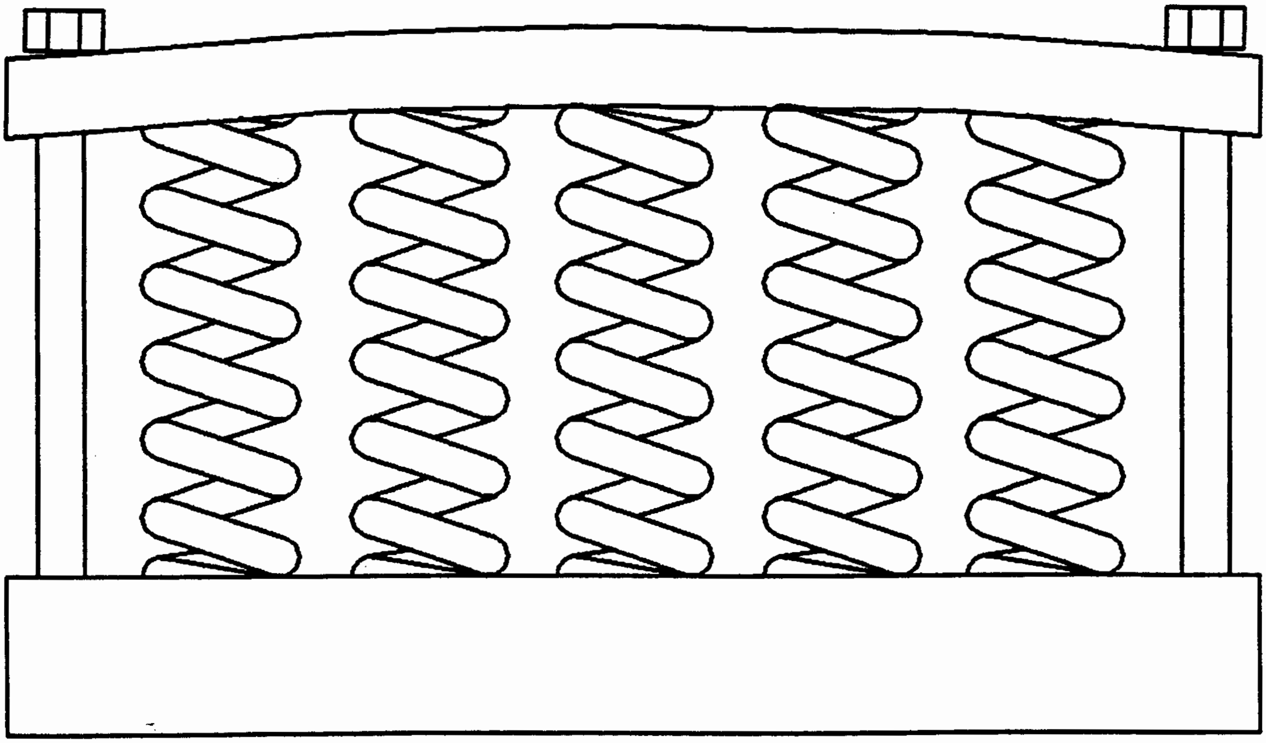


APPENDIX H

STEEL SPRINGS LINEAR COMPRESSION RATE

Appendix H

Steel Springs Linear Compression Rate

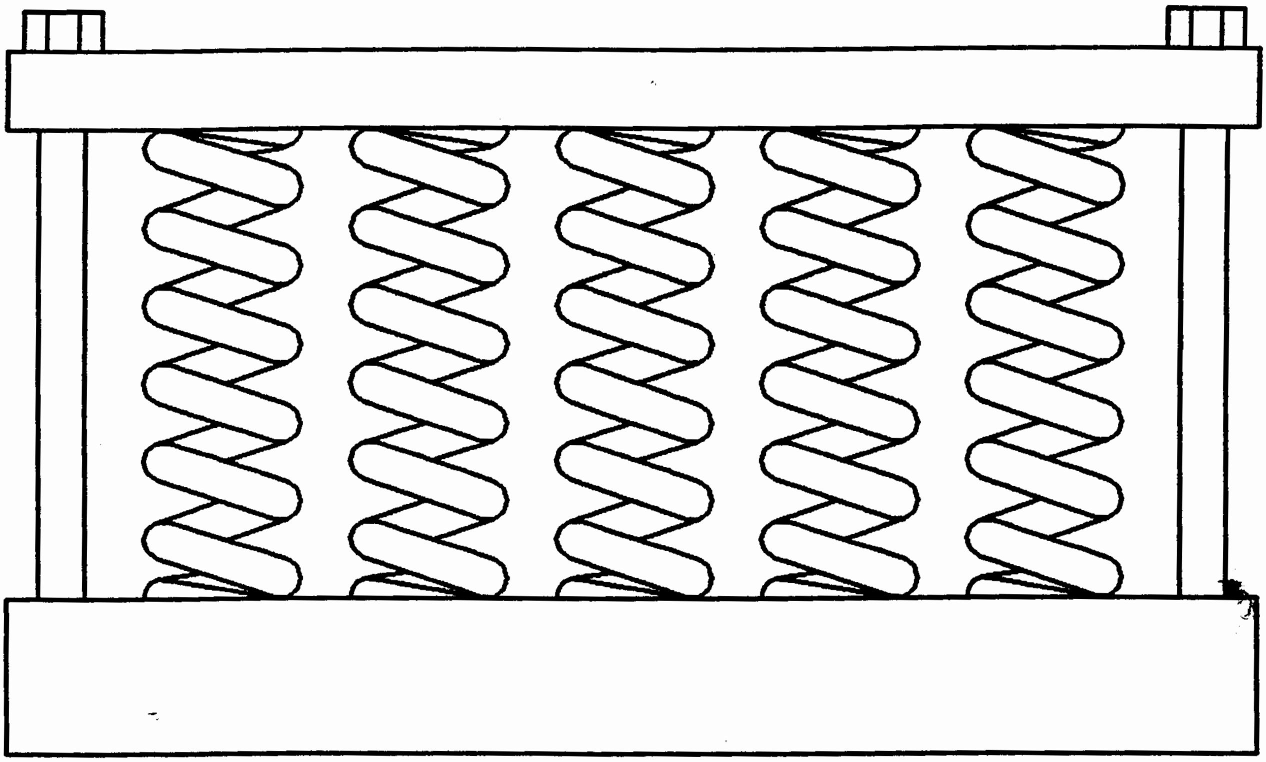


APPENDIX I

STEEL SPRINGS NON-LINEAR COMPRESSION RATE

Appendix I

Steel Springs Non-Linear Compression Rate



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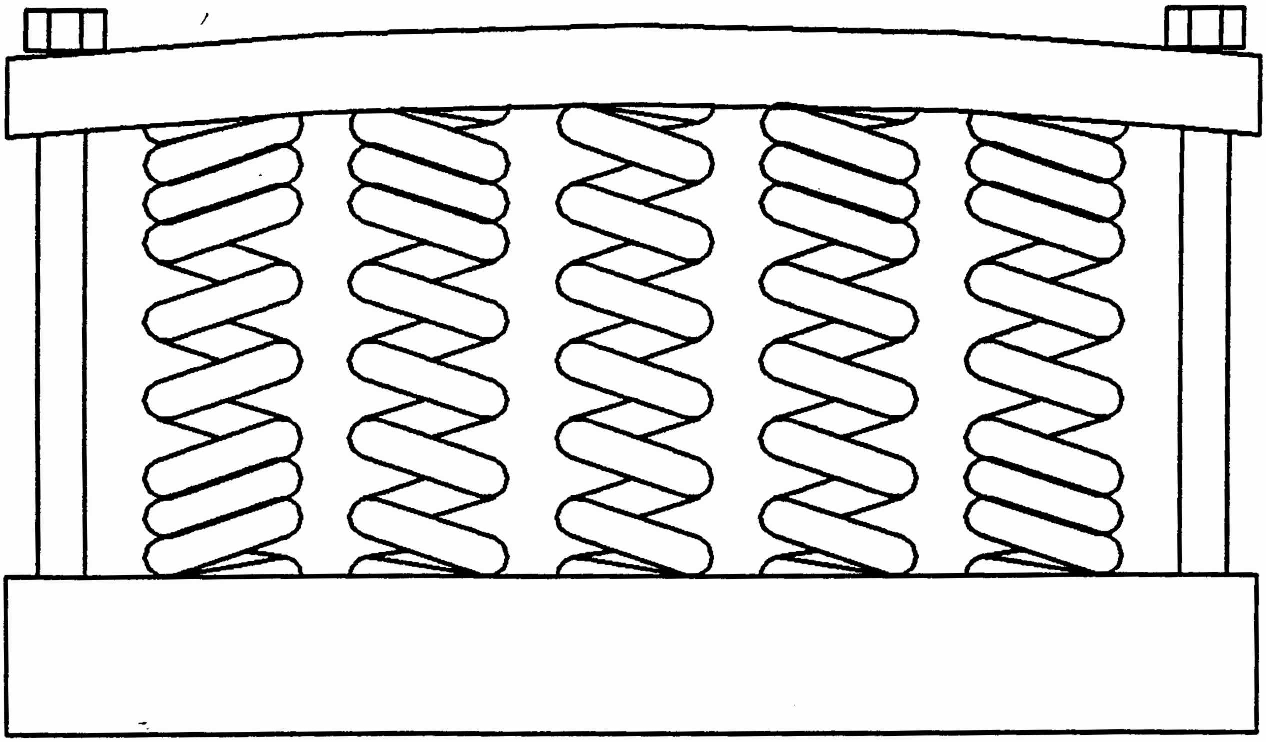
Appendix J

Steel Springs Non-Linear Compression Rate



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Appendix K

Steel Springs Non-Linear Compression Rate