IPRO 321

Enhancing Reliability and Performance of a Paper Shredder

FINAL REPORT

Summer 2007

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Sponsor

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1.0 Introduction

IPRO 321 is a continuing IPRO this summer, from the Spring 2007 semester, aimed at improving the performance of a paper shredder. This semester our sponsor, The Manhattan Group, directed the IPRO team to concentrate on only one specific Royal paper shredder, which they have provided for us to work on.

2.0 Background

General Product Description

Document shredder machines, commonly referred to as paper shredders, have been used in the office environment for many years. Once sold and used exclusively in offices, paper shredders can now be found in consumers' homes. Reasons for the increased use of paper shredders by consumers may be to aid in the prevention of identity theft and for use in the home office. A paper shredder performs the same function whether the machine is used in the office or home; however, paper shredders for the office are typically larger in size and are designed for high usage, whereas shredders for the home are typically smaller and designed for light to medium usage.

Market Information

Approximately 20% of all households (about 22 million) have at least 1 paper shredder. There were an estimated 10 million paper shredders sold for home and office use during the last fiscal year. The number of sales (home and office) is expected to increase by approximately 20% per year (U.S. CONSUMER PRODUCT SAFETY COMMISSION).

Project Specifics

The IPRO team had an opportunity to meet with the president of The Manhattan Group, Mr. Seth Lewis, and ask questions regarding the scope and expectations of the project. The model of the paper shredder the team worked on is the most affordable cross cut model sold by the Royal brand (Model #Bonsen C050). Currently the distribution of this model is exclusive to Europe. The goal is to have the unit distributed in retail locations such as Target, Staples, Office Max, and other local level retailers in the U.S. This model is intended for mainly home use. The present mechanical design allows a gear train to withstand about 300 cycles at maximum sheet capacity, which should permit the shredder to operate longer than the one year covered by the manufacturer's limited warranty, under the assumption of typical home use of the product.

The IPRO team has access to the documents uploaded to the iKNOW website by the students involved in IPRO 321 from the previous semester. Unfortunately, after the detailed verification of those documents, we found a lack of any specific and/or detailed data from the tests performed last semester. One relevant piece of information that has been learned from the documentation is that the measurement and calculation of the force produced by the shredder was not quantified last semester. The force was different in each measurement and the formula to calculate the force was not established.

This semester's team has bought the equipment – according to our limited budget – needed in order to perform appropriate tests. The team also performed research in Staples and Office Depot stores, to become more familiar with the products available and to help us pinpoint our model's weaknesses. Additionally, the team disassembled the Royal shredder and the market-leading shredder to compare all the interior mechanisms and try to come up with a way to improve the Royal design, avoiding any potential patent infringement. We also contacted Underwriters' Laboratories, but they could not provide us with any documentation that would be applicable.

The team has been divided into three sub-teams according to the project opportunities provided by The Manhattan Group (listed in the Goals section of this project plan). Additionally, members were encouraged to switch between sub-teams if more human resources were needed in various areas as the project progressed. We realized promptly that force required by the shredder depends strongly on the gear train, and that the gear train is the second main cause of the noise next to the motor, therefore showing how interrelated each of the sub-teams' topics really were.

Our extensive research and tests made us aware that the preliminary goals of this project are strongly related and dependent to each other. These findings often forced us to work as one group to achieve common goals and satisfactory results.

3.0 Objectives

The main objectives for IPRO 321, as dictated by our sponsor, were: to determine the amount of force required to cut various quantities of paper, and then create a computer simulation based on that data; to optimize the gear train so that the system would be able to withstand at least 500 cycles at maximum sheet capacity; and to reduce the amount of noise emitted by the shredder by 10 decibels. To address these objectives, the IPRO team brainstormed various tests: sound tests (including frequency and sound dampening material tests), a strobe light test to measure the speed of the motor, and a test to determine the motor's specific torque output. Lastly, a survey was created to not only help with market research, but also to support the IPRO team's conclusions about the results of the experiments. The main goal/purpose for IPRO 321 was to accomplish most, if not all, of the objectives outlined by the sponsor while attempting to avoid incurring great costs to accomplish the objectives.

4.0 Research Methodology

RPM Measurement

The high-frequency range noise is assumed to originate from the gears. Taking into account acoustics, the RPM of the gear (i.e. the speed at which it rotates) is proportional to the frequency of the noise it generates. Thus, measuring the RPM at different stages of the gear train would show where the high-frequency noise originates.

The RPM measurements were conducted with the Monarch Instrument Nova-Strobe DA Plus (Figure 1).

<Fig.1 Nova Strobe DA Plus>

Using the TTL external trigger of the Nova Strobe provided a relatively simple and quick procedure in measuring the RPM. The RPM's at the first drive (i.e. motor shaft) and at the final drive (i.e. shredding blade shaft) were measured for both the Royal and leading-brand shredders, respectively.

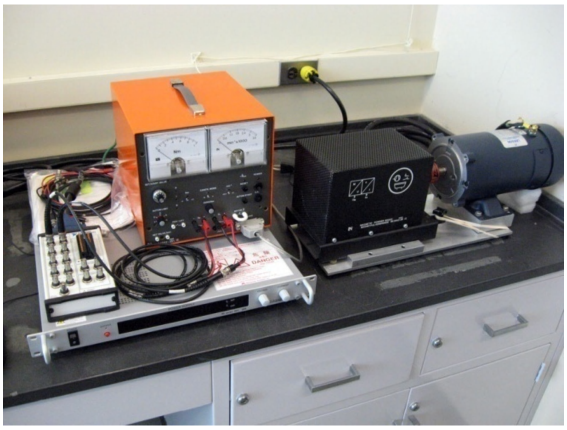
RPM measurement at the motor shaft was enabled using a cardboard disk of approximately 1 inch diameter and a small reflective sticker applied at the outer diameter of the disk. The disk was then attached to the motor's shaft. Hot melt glue was applied at the motor shaft/disk attachment in order to avoid slipping and thus reducing any inaccuracies. The final drive gear had a sufficiently large diameter enabling us to skip the cardboard disk step and apply the reflective tape directly to the gear.

One of the team members operated the strobe while another member operated the shredder. The strobe operator aimed the red light of the external trigger on the disk. Once the motor started to rotate, the strobe gave a reading of the RPM on its digital display. The same procedure was repeated for both shredders.

Torque Measurement

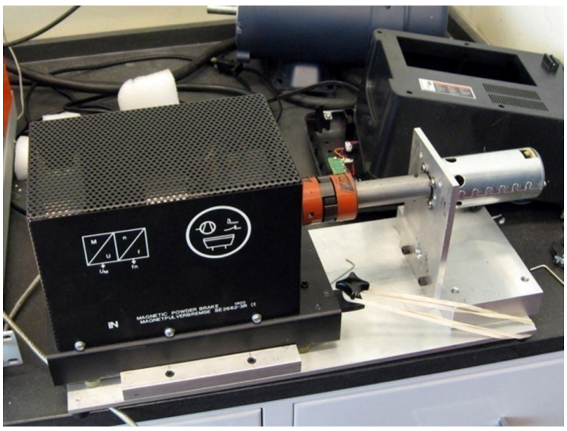
Torque is one of the key features of a motor. It can be thought of as ‘rotational force’ or a measure of the ability of a rotational motion to do work. Thus, the torque of the motor in a shredder could be an indicator of the unit’s ability to shred a certain amount of paper.

The torque measurement was carried out using the Lucas-Nülle SE2662 Magnetic Power Brake Dynamometer as shown in Figure 2



<Fig.2 Dynamometer Setup>

This apparatus gave the input torque value, as well as a voltage output, via an analog display. In order to fit the shredders’ motors (which were smaller than the typical test motor), a custom coupling and mount were built, as shown below.

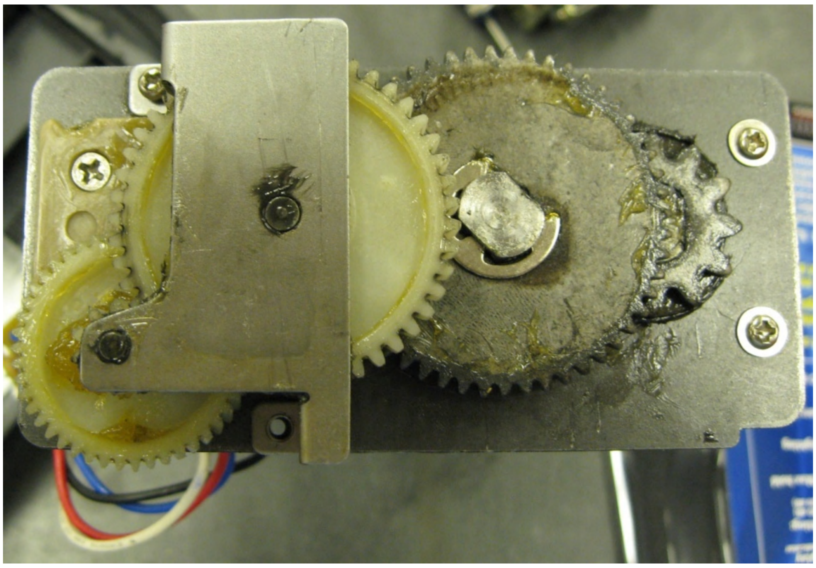


<Fig.3 Motor Mount>

The measurements were taken for both motors (one from the Royal shredder and one from the leading-brand shredder). The voltage output was connected to a laptop computer through a shielded connector block (National Instruments BNC-2110). Using the LabVIEW software, the data on voltages was collected at a rate of 250 scans per second.

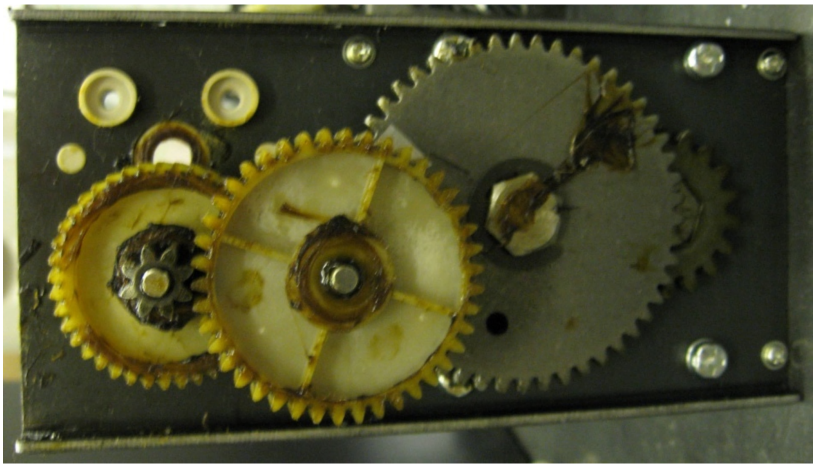
Gear Train/Gear Ratio

The Royal shredder being analyzed was disassembled and found to consist of an electric motor which was used to power several sharp cutting blades through a system of gears. One of the objectives given was to optimize this gear system (or gear train). The gear train of the Royal shredder is shown below.



<Fig.4 Royal Shredder Gear Train>

A reverse engineering process was adopted by doing some market research. The best selling personal use shredder on the market was purchased and analyzed. It was dismantled and observed to include the exact same gear train/gear configuration as the Royal shredder. The gear system of the leading-brand shredder is show below.



<Fig.5 Leading-Brand Shredder Gear Train>

Gear ratio is a term used in the analysis of gear trains. It is a comparison between the number of turns of the input gear (powered gear) and the number of turns of the output gear (final drive). For instance, a gear ratio of 1:5 describes a gear train in which the final drive rotates 5 times as fast as the powered gear. A gear ratio of 5:1 describes a gear train in which the powered gear must rotate 5 times in order for the final drive to rotate once.

The gear ratio of the Royal shredder was calculated and measured. This data was used to compare the gear train of the Royal shredder, which had to be optimized, to that of the higher end shredder.
In order to ensure the validity of the calculated data, the RPM readings were also used to find the gear ratios (the *Results* section contains the details of these calculations).

Sound

The sound team had an objective to reduce the noise level of the shredder by 10dB as directed by Seth Lewis, the sponsor of this IPRO team. Ultimately, the goal was to make a shredder that is most pleasing to the ear, not necessarily a quantified amount quieter. With this objective, the sound team set out to study other high-end shredders to see what it was that made them quieter than others. One constraint that was kept in mind was the fact that this shredder was to be marketed as an affordable model.

During initial inspection of the Royal shredder, the team had several ideas to decrease sound output from the shredder. These possibilities included: a more enclosed paper basket (to counter the open hole), the use of sound dampening materials in the assembly, use of a belt drive instead of the gear train, elastomeric motor mounts, slowing down the motor, and reducing electric spikes which caused higher motor speeds before and after paper feeding.

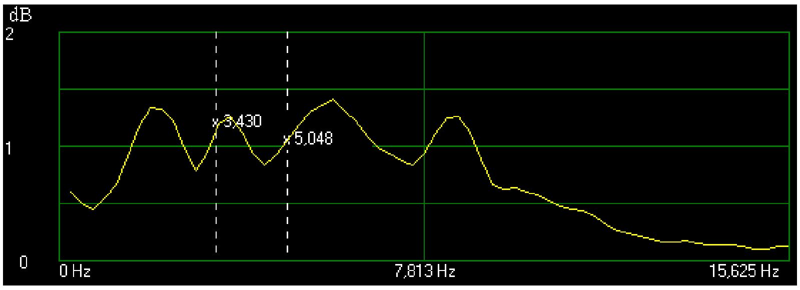
Acoustics Testing

The first study done was to measure the sound levels of the Royal shredder from a measured distance. Tests were then performed to determine the sound level of the leading-brand shredder, which appeared to be much quieter and to produce a much more pleasing sound.

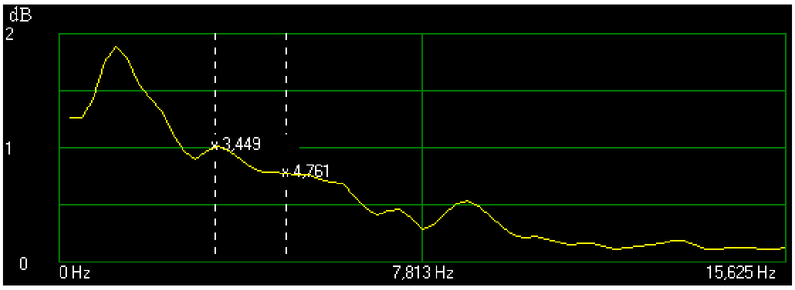
A decibel meter was deemed the best device to perform the sound measurements. For all readings, the microphone on the dB meter was placed exactly 3 feet from the source of the sound.

The tests showed that the dB levels of the Royal and leading-brand shredders were not so different. In fact, the variances in the readings reveal that it may not be the most important factor.

As a result of the dB level testing, the team decided to conduct an FFT based spectrum analysis of the acoustic characteristics of the two shredders. This was decided because there was general consensus that the Royal shredder had a higher pitched sound that was not as pleasing to the ear as the lower frequency sound coming from the higher end shredder.



<Fig.6 Royal's Spectrum>



<Fig.7 Staples' Spectrum>

Also, speed tests were done on the motors to determine the difference in motor speed which may cause high frequency noise.

Finally, testing was done to the shredder on different surfaces and with a vibration-resistant foam collar around the wastebasket. It was predicted that vibrations make a huge impact on the level of sound coming from the shredder.

5.0 Assignments

Opeyemi Babatola *Mechanical Engineering*

Skills/Experience

- Pro/E, AutoCAD, Matlab
- Various mechanical related projects
- Artistic skills sharpened by being comics editor of TechNews for a year

Kelly Bergren *Applied Mathematics*

Skills/Experience

- Knowledge of Maple and Microsoft Office
- Access to materials and tools through work in hardware store
- Pays attention to detail

Luke Cho *Mechanical Engineering*

Skills/Experience

- AutoCAD, Pro/E, MS Project, Adobe Photoshop
- Mechanical analysis experience from previous projects and 400 level MMAE courses
- Multicultural Experience

Erik Dill *Computer Information Systems*

Skills/Experience

- All around computer skills through years of study of computers and computer systems
- Leadership skills through military service
- Creative and a quick learner

Saul Esparza *Electrical Engineering*

Skills/Experience

- Industry experience working for De La Rue
- Experience with electrical systems and circuits
- Experienced at time management and multitasking

Michael Kim *Computer Engineering*

Skills/Experience

- Knowledgeable about sound dampening and isolation through work on car vibration reduction
- Experience with AC motors with good understanding of how they work
- Familiar with the circuitry board in use

Daniel Mendez *Electrical Engineering*

Skills/Experience

- Experience with electrical systems through higher level electrical engineering courses
- Goal oriented
- Helpful and resourceful

Mithun Michael *Electrical Engineering*

Skills/Experience

- Java, C++, MS Project
- Interest in acoustic dampening
- Hardworking, Task oriented

Joey St. Clair *Computer Science*

Skills/Experience

- Java, Sound analysis software
- Programming skills acquired through years of classes and project
- Inquisitive, Desire to discover force equations that no one has ever accomplished

Adam Stultz *Biomedical Engineering*

Skills/Experience

- Biomedical Engineering background makes for an innovative mind
- Dexterous and good at constructing models
- Motivated by challenges

Sebastian Zielinski *Computer Engineering*

Skills/Experience

- Experience designing computer simulations
- Knowledge and experience with computer system analysis
- Multicultural experience and people skills

Team Leader

Luke Cho

Sub-Teams

Force-Load Relationship

- Adam Stultz
- Joey St. Clair
- Sebastian Zielinski (Sub team Leader)

Gear Train Optimization

- Luke Cho
- Saul Esparza (Sub team Leader)
- Opeyemi Babatola

Noise Reduction

- Daniel Mendez
- Erik Dill (Sub team Leader)
- Kelly Bergren
- Michael Kim
- Mithun Michael

Sub-team Responsibilities Breakdown

Force-Load Relationship: Determine the amount of force needed to cut 6, 8, and 10 sheets of 20 lb. paper taking into account the length and width of the shred

Gear Train Optimization: Design an efficient gear train that optimizes the number of gears and minimizes the motor size

Noise Reduction: Develop acoustical sound dampeners to reduce the amount of noise created during the shredding process by 10 decibels

Individual Member Responsibilities

Force-Load Relationship:

- Consulting (Sebastian)

- Determine forces needed to be measured & machinery to measure them (Adam, Joey)
- Determine force required to shred certain amounts of paper (Adam, Joey, Sebastian)

Gear Train Optimization

- Consulting (Luke, Saul)
- Determine materials and material properties (Saul, Yemi)
- Gear Mechanical analysis/determining failure modes of gears (Luke, Yemi)
- Combine data to make a more efficient gear train (Luke, Saul, Yemi)

Noise Reduction

- Consulting (Kelly, Erik)
- Set up equipment to measure acoustic data (Michael)
- Determine where the most sound is coming from (Mithun, Erik)
- Determine how to reduce noise in the problem areas (Daniel, Michael)
- Test results (Kelly, Daniel, Mithun)

6.0 Obstacles

Throughout the course of this project, the team was faced with a number of obstacles. The first obstacle that we faced was the shortened semester. In order to overcome this obstacle our team developed an aggressive schedule that would allow us the best opportunity to complete our goals in the given amount of time. Secondly, our already limited time was further reduced by mandatory events that took away from classroom and lab time. This was overcome by working more efficiently when we were able to focus on our project. A final obstacle that our team faced was limited access to our testing equipment and the laboratory. In order to overcome this obstacle we were able to obtain a key to the laboratory so that we could use our testing equipment outside of class time.

Although we were able to overcome the majority of the obstacles we faced, there were some that did have an impact on our results. First, we wanted to contact a member of the previous semester's IPRO team in order to find out what mistakes their team made so that we would not repeat them. However, despite repeated attempts to contact the team member, we were unable to accomplish this task. Due to this lack of communication, we most likely repeated some of their past mistakes, wasting some of the limited time we had. Secondly, due to the fact that this was a summer semester, many of the professors that we would have liked to consult about our project were unavailable. Finally, although we did have access to a lab room, the lab was not sufficiently stocked with tools. This caused our testing procedures to take longer than they should have because we had to make do with what we had. For future groups our team recommends that either a better lab is secured for testing, or that tools are purchased immediately.

7.0 Results

RPM

Each measurement was taken 3 times; the average values are tabulated in the following table:

Royal	Staples
Motor(first drive)	
15000 rpm	13400 rpm
Final Drive	
68.4 rpm	29.7 rpm

<Table.1 RPM Readings>

The readings show a distinct difference in speed at the final drive. While the two motors operate at a comparable speed (10% difference), the Royal's final drive rotates at more than twice the speed of the leading-brand shredder's final drive. This explains the high-frequency noise of the Royal shredder, which comes from the higher rotational speed at its final drive.

Torque

The torque readings are given by a differential voltage, where 1V = 1Nm. The data was tabulated in Excel and the maximum value along with the average value for each test is tabulated below.

	Royal	Staples
Test 1	0.159	0.366
Test 2	0.157	0.247
Test 3	0.166	0.340
Average	*0.160*	*0.317*

<Table.2 Torque Readings>

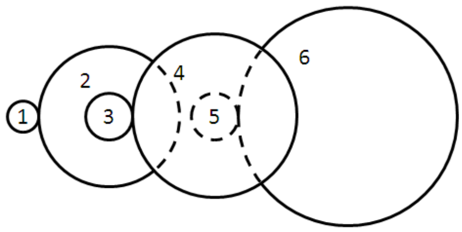
The Royal motor produced 0.160 Nm while the leading-brand shredder produced 0.317 Nm, which is almost twice the torque of the Royal motor. This is a significant difference, taking into account the fact that the two motors rotate at nearly same speed. This would mean if the higher end motor were to replace the Royal motor, the shredder would (in theory) hold twice as much load, or last twice as long with the same load restrictions.

Gear Train/Gear Ratio

It was noted that the leading-brand shredder was significantly quieter than the Royal shredder once both were operated. However, several inferences about the differences between the shredders were made once both had been dismantled:

- The gears used in the leading-brand shredder were much larger
- There was a generous amount of lubrication between the gears in the leading-brand
- The blades of the higher end shredder rotated much slower than the blades of the Royal

This led to a conclusion that the gear ratios of the two shredders were quite different and had to be studied. The procedure used to calculate the gear ratio was as follows:



<Fig.8> Gear Train Schematic

Train Value, $e = \frac{\text{Product of Driving Tooth Members}}{\text{Product of Driven Tooth Members}}$

Driving Gears
N_1 = 5 Teeth
N_3 = 10 Teeth
N_5 = 10 Teeth

Driven Gears
N_2 = 46 Teeth
N_4 = 47 Teeth

N_6 = 52 Teeth

$$e = \frac{500}{112424} = 4.447 \times 10^{-3}$$
$$1/e = 225$$

$\Rightarrow$ Gear Ratio = 225:1 (Speed Reduction)

Similar calculations of the gear ratio of both the Royal shredder and the leading-brand shredder were made using the values obtained from the RPM readings. These calculations are detailed below.

Royal:

Gear Ratio = $\frac{\text{RPM of Driving Gear (Motor Worm)}}{\text{RPM of Output Gear (Final Drive)}}$

Gear Ratio = $\frac{15000}{68.4}$

$\Rightarrow$ Gear Ratio = 220:1 (Speed Reduction)

Staples:

Gear Ratio = $\frac{13400}{29.7}$

$\Rightarrow$ Gear Ratio = 450:1 (Speed Reduction)

It can be deduced from this data that the leading-brand shredder has a reduction (from the gear train) double that of the Royal shredder.

Sound

From the data, it was obvious that the original assumption of the frequency being lower on the leading-brand shredder was correct. The dominant frequencies from this higher end shredder lie in the lower frequency range while the Royal shredder has an even frequency ranging from low to high. This suggests that the main reason behind the Royal shredder appearing to be louder was the higher, more irritating frequency output.

This is not to say that the team completely ignored the dB readings. There was a definite, albeit small, decrease in decibels coming from the leading-brand shredder. Upon initial inspection of the casing, it was determined that the case used heavier plastics and shrouded the entire mechanism with no openings to the motor except through the paper feed. This was confirmed by again testing the leading-brand shredder with the paper basket ajar.

This was not contrary to what the team had figured would be a better solution initially. So taking into account the motor speeds and subsequent gear ratios, it seemed that the slower motor would greatly decrease noise levels in the upper frequencies and thus produce a more pleasing sound.

The other method of attaching a foam collar did actually produce a fairly large (4dB) sound difference. Considering the possible costs and other factors, it was determined that this would definitely be a viable option to reduce noise in the Royal shredder.

8.0 Recommendations

RPM/Gear Train/Torque

Although implementing new mechanical components/devices requires an in-depth trial-and-error test, which is a time-consuming and tedious task, it is possible to make predictive assumptions based on the findings from the research.

First, modifying the current gear train to a new gear train with a gear ratio of about 400:1 by enlarging select gears would allow the gear train to rotate at a slower speed. This reduces the peak frequency level of the noise the gear train generates.

Furthermore, the larger gears necessary for the reduced gear ratio also reduce the contact stress, thus extending the life of the gear train, and therefore the whole paper shredder.

Another applicable improvement is increasing the torque of the motor, namely, replacing the motor with a higher torque rating. This would increase the shredding capacity, which would not only increase the number of papers that can be shredded, but would also allow a smoother operation. Also, the increased power would help to avoid possible mechanical failure such as jamming, gear bursting, etc.

Development and implementation of an enclosure, constructed with a sound dampening or vibration reducing material, housing the gear train would result in further noise reduction.

Sound

After our testing we have determined that a majority of the noise issues would be resolved by modifying the gear ratio. This would reduce the frequency of the sound produced, thus making the noise of the shredder less harsh to the ear.

Another recommendation that our team had for reducing the noise of the shredder was to simply install an isolating gasket between the motor assembly and the waste basket. This would limit the vibration transmitted from the motor to the plastic basket and reduce the decibel output of the shredder by up to 5 dB.

9.0 References

Robert L. Norton, 2005. Machine Design: An Integrated Approach. Prentice Hall, New York.

Dennis P. Townsend, 1991. Dudley's Gear Handbook. Mcgraw-Hill, New York.

Richard G. Budynas & J. Keith Nisbett,2008. Shigley's Mechanical Engineering Design. McGraw Hill, New York.

George Jones & June Ferril, 2006. The Seven Layers of Integrity. AuthorHouse, Bloomington, Indiana.

10.0 Acknowledgements

Many of our accomplishments are attributed to the entire IPRO team who worked diligently in order to obtain results in a condensed time period. However, none of the results could have been achieved if it weren't for the lending hands of our sponsor and supporters. We would like to thank Dave, from Staples, who gave us more than just "store-clerk" helpful information on how paper shredders function. We would also like to acknowledge Russell Janota, the MMAE lab technician, who provided us with the necessary lab equipment and space in order to conduct our research. In addition, we would like to express our gratitude to Professor William Maurer, who gave us the motivation to succeed in many of our objectives and gave us advice in handling individual tasks and procedures so that our project and presentation could be a success. Furthermore, we are very grateful for the professional aid provided by Dr. Sheldon Mostovoy, a Mechanical Engineering Professor at the Illinois Institute of Technology. Dr. Mostovoy's help was critical to our research, which allowed us to progress in the IPRO project, and he also provided us with access to a restricted lab that allowed us to conduct further studies on the motor of the paper shredder. Finally, and most importantly, we would like to thank Seth Lewis, our sponsor and President of the Manhattan Group, who provided us with the financial support, useful insight on the paper shredder market, and goals for the IPRO project to carry out in order to meet his needs.