Project 2: Xerox Paper Velocity Measurement Device

EDSGN 100: Section 021

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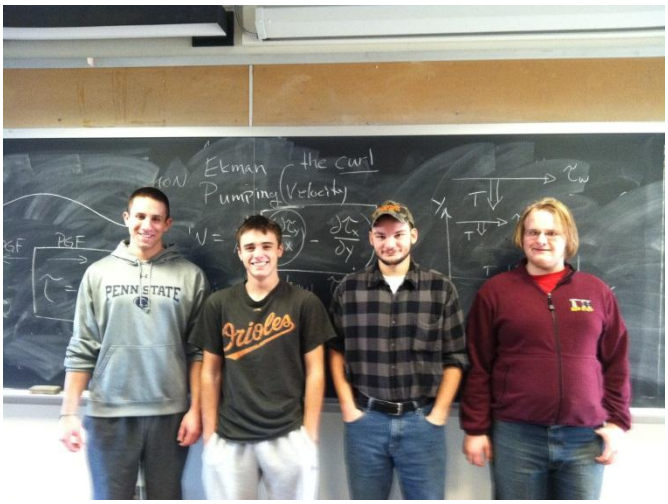
SEAL TEAM VI



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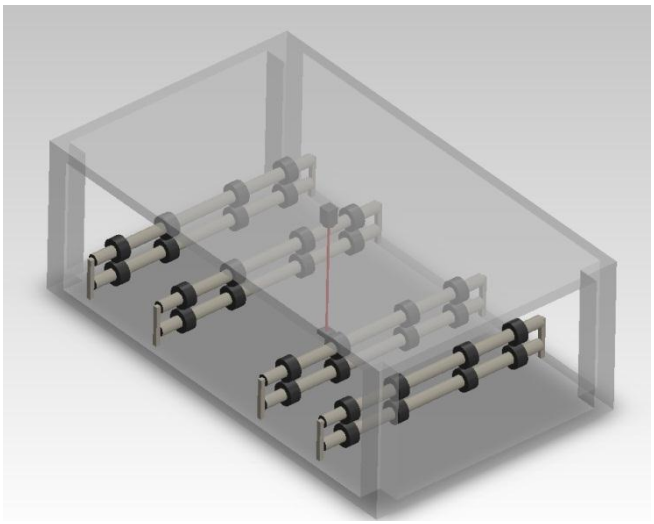


Abstract

One of the greatest aspects of engineering design is the amount of real world application it has. We were introduced to real world application through Design Project 2, sponsored by Xerox. This project presented us with the challenge of developing a paper velocity measurement device for the Xerox iGen4 printing system. Xerox's iGen4, a gigantic, extremely complex printing press, produces perhaps the most accurate printing job on the market today. Creating a paper velocity measurement device for the iGen4 would further increase the accuracy and success of it. Xerox then turned to Seal Team VI, a group of four EDSGN100 students at Penn State, to design this device. Xerox laid out various specifications and needs, such as measurement tolerance and cost effectiveness. Armed with vast knowledge of the engineering design process, we set out to begin our design. We worked through identifying the problem, identifying customer needs, concept generation, concept development, concept selection, expanding upon our concept, building models to communicate it, and compiling our information into an oral presentation as well as a written report.

Our design solution is a single vertical trip laser setup, located in any horizontal paper path of the iGen4, that measures the velocity of a sheet of paper through recording the amount of time it takes for a piece of paper of any determined length to break the path of this laser. Our concept divides the distance, or length of the paper, by the time measured to calculate the actual velocity of the paper. This is much more accurate than the current nominal velocity used by the iGen4. By using this velocity, an accurate, perfectly aligned printing job is ensured every time. Our design successfully helps to improve Xerox's iGen4 printer

Introduction

The iGen4 printer, created by Xerox, is an enormously complex printing system. Taking up the space of a small room and being perhaps the most customizable printer on the market, the iGen4 is a valuable asset for any serious printing business. With a cost exceeding $1 million, you truly get what you pay for with the iGen4 printer – the highest quality printing job possible spanning hundreds of different printing configurations.

Figure 1. The Xerox iGen4 Printer

As a piece of paper moves through the paper path of the iGen4 printer, drive rolls are responsible for moving the sheet through the path. In order to ensure a perfectly accurate printing job, many variables of the paper must be taken into account, such as velocity. The velocity of the sheet moving through the path must be known in order to create proper alignment for any type of printing job. The velocity is typically measured as the nominal velocity, which is an estimated paper velocity based on the speed of the drive rolls that move the paper through the path. Unfortunately, the velocity of the paper can vary due to several significant variables, such as paper thickness and finish. This creates a slight deviation from the

nominal velocity of the paper, called the actual velocity. Currently, the iGen4 printer does not measure the actual velocity of the sheet of paper as it moves through the path.

Our team set out to design a device that detects the actual velocity of an 8.5”×11” sheet of paper moving through a simple paper path in the iGen4 printer. This sheet should be moving somewhere between 250 to 750 mm/s. The paper stock velocity needed to be measured within a tolerance of ±0.25%. Therefore, our device must accurately measure the actual velocity of a piece of paper within about 4 mm/s. Clearly, this device must be extremely accurate in order to ensure a top-notch printing job that is always present with Xerox products. In order to clearly communicate our design, we were also tasked with creating a model of a simple paper path. With this model, we were also tasked with creating a model of our velocity measurement system. Finally, we were also tasked with documenting a step-by-step measurement procedure that clearly communicates how our device functions. Overall, this Xerox tested our design skills and introduced us to real world application of engineering design.

Demand Analysis/Customer Needs

Seeing as Xerox is the premier company associated with high quality printing, document management, information technology, and business services, it is expected that we would create a high quality device in order to complement the high quality design and functionality of the iGen4 printer. From a business perspective, Xerox is concerned with continually improving their products in order to continue to produce cutting-edge technology for their respective markets; in this case, the paper printing and copying market. It is obvious that the iGen4 printer strives for perfection in paper printing and copying by disregarding size restrictions in order to

ensure a printing job of immaculate quality. For example, the iGen4 contains its own temperature regulation system. The vast amount of variables that the iGen4 successfully encompasses and manages during a printing job reflects directly onto its end product: the highest quality printing and copying job currently on the market. The implementation of a paper velocity measurement device would further increase the perfection achieved by the iGen4. A solution to the problem of measuring paper velocity is needed to further enhance the accuracy and precision of the iGen4 printer. In essence, this establishes Xerox as the customer that we are designing for.

In designing our velocity measurement device, we had to take into account the needs that Xerox explicitly and implicitly expressed. For example, our device must measure the actual velocity of the paper, which is dependent on various aspects of the paper, such as its thickness and finish. Therefore, our velocity measurement must be independent from these paper characteristics, meaning that it will produce an accurate velocity measurement no matter what type of paper is used. Another explicit need stated by Xerox is that our design must be able to be effectively communicated through the creation of models and a step-by-step procedure. Finally, our problem statement also stated various needs pertaining to accuracy, such as how our device must measure velocity within a tolerance of 0.25%.

In order to understand basic customer needs that our device must satisfy, we designed an Analytical Hierarchy Process matrix (Figure 2). This matrix establishes five main customer needs that we must meet and weighs them against each other in order to establish their

relative importance in our design. Doing so allows us to identify which customer needs our design must cater to the most.

Selection Criteria	Accuracy/Precision	Ease of Implementation	Efficiency	Ease of Use	Durability	Total	Weight
Accuracy	1.00	1.33	2.00	4.00	5.00	13.33	**0.39**
Precision/Reliability	0.75	1.00	1.33	2.00	4.00	9.08	**0.26**
Cost	0.50	0.75	1.00	1.33	2.00	5.58	**0.16**
Ease of Implementation	0.25	0.50	0.75	1.00	1.33	3.83	**0.11**
Durability	0.20	0.25	0.50	0.75	1.00	2.70	**0.08**
					total	34.53	1.00

Figure 2. AHP Matrix

The five selection criteria, or customer needs, that we chose to evaluate were: accuracy/precision, ease of implementation, efficiency, ease of use, and durability (Figure 2). These five selection criteria are characteristics of our design that it must cater towards. By using this AHP matrix, we compared these selection criteria to each other and determined their relative importance, or weight. Overall, our selection criterion with the highest importance, or weight, is accuracy/precision, followed by ease of implementation, efficiency, ease of use, and durability. By creating these relative weights for our selection criteria, this enabled us to identify which design characteristics were most important. In addition, this enabled us to select a design concept in the concept selection phase that most effectively meets these selection criteria. The AHP matrix is an invaluable tool that helps understand customer needs as well as how to select the appropriate design concept.

Preliminary Concept Development and Generation

Perhaps one of the most important phases of engineering design is concept generation and development. After identifying the problem and what needs the design must meet, it is up to the individual team members to create ideas, or concepts, for the design at hand. In this stage, it is important to note that concepts are solely being created and documented, not judged nor selected.

For our initial concept development stage, all four team members met together in person in the HUB lobby for a forty five minute long brainstorming session. In this brainstorming session, we followed the "Four C's" of the brainstorming process: no complaining, no criticism, no cell phones, and no condemning. By doing this, we effectively generated concepts without judgment. Doing so allowed us to come up with an excess of design concepts to choose from during the concept development and selection stages of the design process. Our team brainstormed two concepts per team member, generating eight total initial concepts (Table 1).

Concept	Description
1	Two trip lasers that measure time of travel from one to the other
2	Laser that measures time for drive roll markings to rotate
3	Physical projections on the drive rolls that trigger switches measuring the rotation
4	Single triplaser setup that measures time of paper travel through a point

5	Laser grid (barcode scanner) that measures time as well as size
6	“Radar gun” that measures the speed of the paper
7	“Trapdoor” that is triggered physically by the paper and then returns
8	2 “trapdoors” that measure time from one to the other

Table 1. Initial Concept Generation

After generating eight initial concepts, the concept development phase began. In this phase, we utilized a system of concept generation, screening, and scoring, called the concept development funnel (Figure 3). Using this system allowed us to effectively choose which concepts we would further develop.

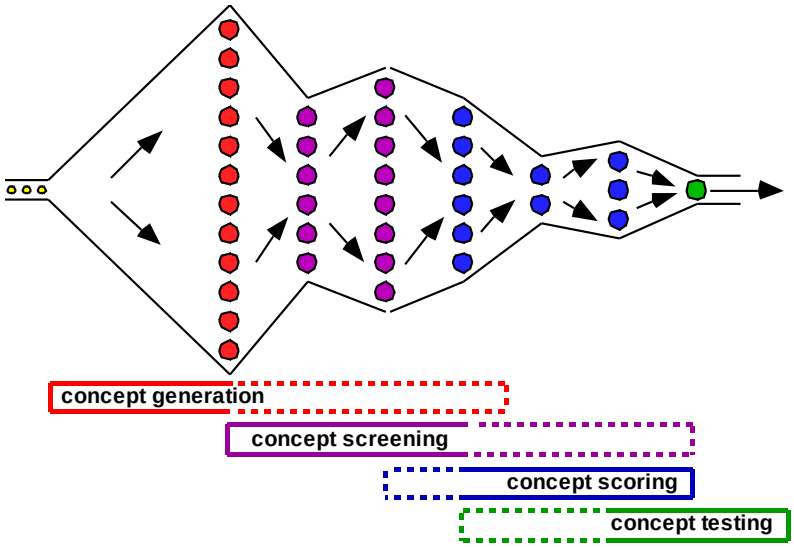


Figure 3. Concept Development Funnel

After generating these eight concepts, concept screening allowed us to judge individual concepts and eliminate obvious concepts that would prove ineffective for our design. For example, we eliminated concepts 7 and 8 because they relied on the sheet of paper physically

triggering “trapdoor” switches that could potentially distort the velocity, shape, and contour of the piece of paper. This would have terrible effects on the overall printing process. In addition, we also eliminated concepts 2 and 3 because they measured the rates of rotation of the drive rolls. The actual velocity of the paper can be different from that of the drive rolls due to factors such as paper stiffness, finish, and weight. Even though the drive rolls could be rotating at a consistent speed, the actual velocity of the sheet of paper could change due to these factors. These two concepts would fail to satisfy many of the customer needs established earlier.

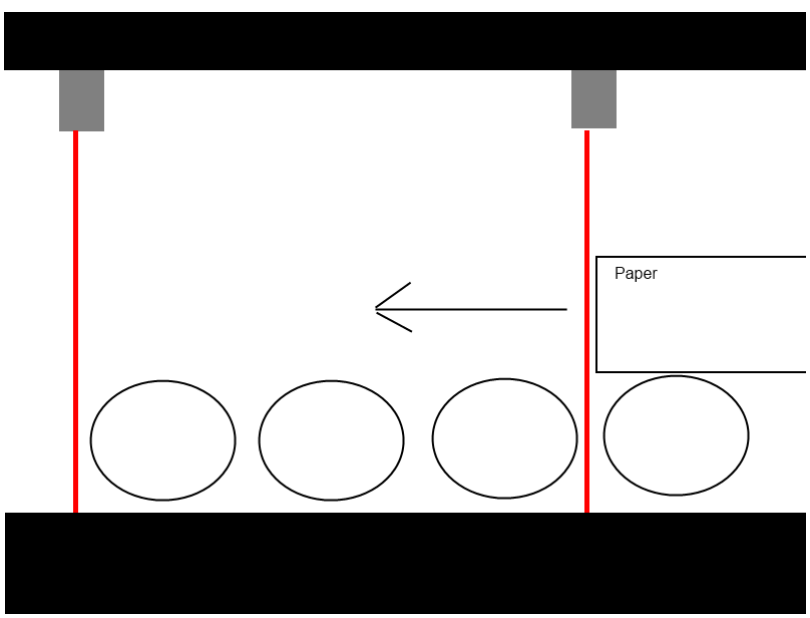
The four remaining concepts, concepts 1, 4, 5, and 6 (Table 1), were then screened in a concept screening matrix (Figure 4) in order to rate how effectively they satisfy the five customer needs generated in the AHP matrix (Figure 2). In this screening matrix, either a (+), (0), or (–) was assigned to each concept based on how it satisfied each customer need. The net score of each concept was then calculated. Finally, the concepts were ranked based on their net scores of how well they satisfied customer needs.

	Concept 1	**Concept 4**	**Concept 5**	**Concept 6 (ref)**
Accuracy	0	+	+	0
Precision/ Reliability	+	+	0	0
Cost	0	+	-	0
Ease of Implementation	0	0	-	0
Durability	+	+	0	0
Pluses	2	4	1	0
Zeros	3	1	2	5
Minuses	0	0	2	0
Net	**2**	**1**	**-1**	**0**
Rank	**2**	**1**	**3**	**N/A**
Continue?	**Yes**	**Yes**	**Yes**	**N/A**

Figure 4. Concept Screening Matrix

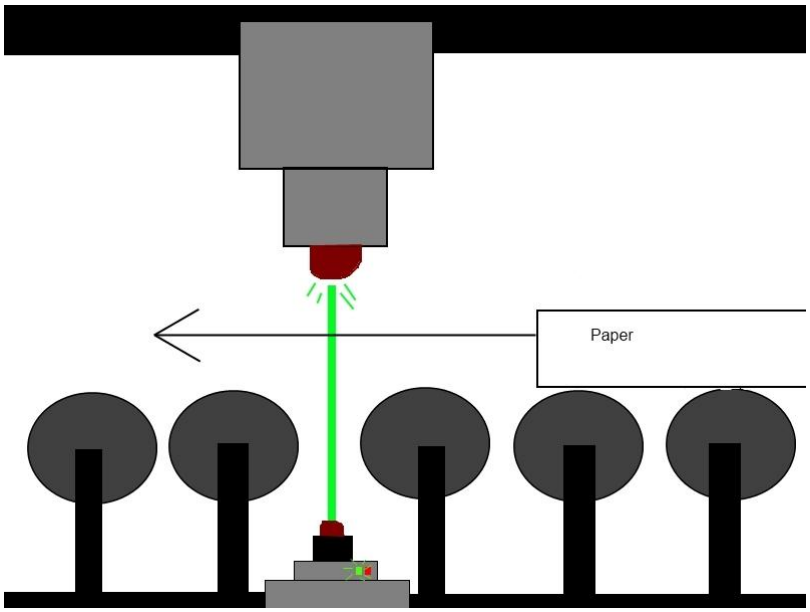
After utilizing the concept screening matrix (Figure 4), we decided to continue development of concepts 1, 4, and 5 based on their scores and rankings.

Concept 1 consists of a system of two vertical trip lasers placed in a straight portion of the paper path. As the paper travels along the baffles, pushed by the drive rolls, it breaks the first laser, triggering a timer. As the paper travels through the path, it eventually breaks the second laser, stopping the timer. The time it takes for the sheet of paper to travel the distance between the two lasers is recorded. Since velocity is a function of distance per unit of time ($\frac{Distance}{Time}$) the distance the paper traveled would be divided by the time measurement, producing a velocity measurement. This velocity is an average velocity measurement of the front of the paper. Sketch 1 shows this concept.



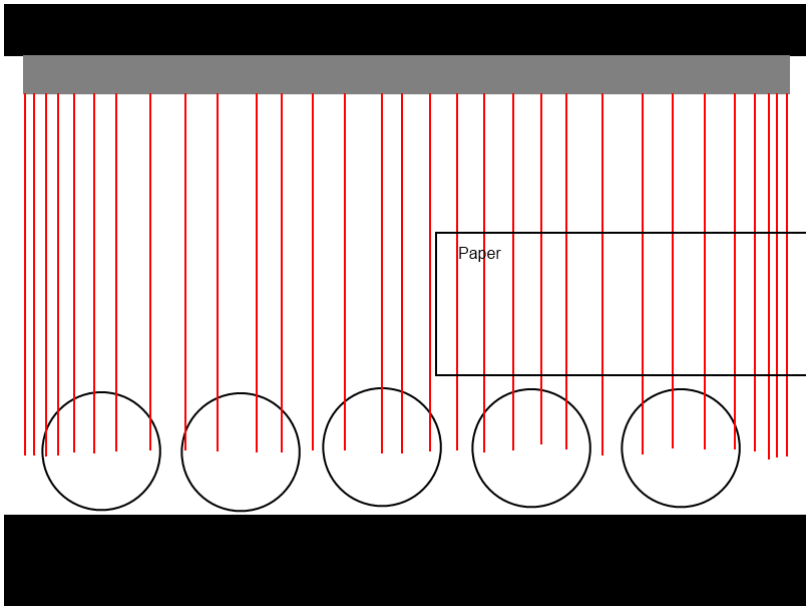
Sketch 1. Concept 1

Concept 4 consists of a system of one single trip laser placed in a straight portion of the paper path. As the paper travels along the baffles, pushed by the drive rolls, it breaks the path of the vertical laser. As soon as the laser's path is broken, a timer begins. The paper then continues through the paper path. Eventually, the laser path is restored once the paper fully passes through it. The timer is then stopped and the time it takes for the paper to travel the distance of its own length is then recorded. Instead of the paper traveling through a set distance, the distance is actually the predetermined length of the paper. Since velocity is a function of distance per unit of time ($\frac{Distance}{Time}$) the distance the paper traveled, or its length, would then be divided by the time measurement, producing a velocity measurement. Again, this is an average velocity measurement, but it measures the velocity of the entire piece of paper rather than the front of it, making this velocity more applicable to the iGen4 than that of Concept 1. Sketch 2 shows this concept.



Sketch 2. Concept 4

Concept 5 consists of a system of a rectangular, vertical laser beam grid placed in a straight portion of the paper path. As the paper travels along the baffles, pushed by the drive rolls, it enters a large grid of many vertical lasers. This grid closely resembles a common barcode scanner used in many convenience stores. The paper travels through the grid, tripping many lasers as it moves. This laser grid works to measure many characteristics of the paper, such as its dimensions. These dimensions are measured by recording the outermost lasers the that the front, back, and sides of the paper break. The distance between these outermost lasers is recorded as the dimensions of the paper. The area can also be determined by measuring the area of the total amount of lasers the paper breaks at one point in time. Of course, the velocity of the paper can be measured, perhaps in multiple ways. This system could use the velocity measurement methods of both concepts 1 and 4. It can measure the time it takes for the paper to travel from one laser to the other, like concept 1, or the time it takes for the paper to travel through one single laser, like concept 4. This would rely on the paper length measurement obtained by the laser grid. This length measurement could only be obtained once the entire piece of paper is located inside of the grid, which calls for a very large laser grid. Due to the variety of extremely large to tiny paper sizes being utilized in the iGen4, this would call for an enormous laser grid system to compensate for all sizes of paper. This is far from ideal as it would have a very high cost for hundreds of lasers as well as take up too much space in the iGen4, requiring perhaps another entire “module.” These two negative aspects of Concept 5 are shown in Figure 4. Sketch 3 shows this concept.



Sketch 3. Concept 5

In the final stage of concept development, concept selection, we created a concept selection matrix (Figure 5) in order to communicate this process as well as choose the best concept. After expanding upon and explaining each concept, Concepts 1, 4, and 5 were given a score on a scale of 1-3 based on how well they met the selection criteria listed in the AHP matrix (Figure 2). Each selection criteria possesses a specific weight, or relative importance, that has been transferred from the AHP matrix (Figure 2). The 1-3 scores of each concept were then multiplied by their respective weights to obtain their weighted score for each selection criteria. These weighted scored were then totaled to obtain a final weighted score for each concept. The concept with the highest weighted score would then be chosen as the concept to develop for this design project! Figure 5 shows this concept selection matrix.

		Concept 1		Concept 4		Concept 5	
Selection Criteria	Weight	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Accuracy	0.39	2	0.78	3	1.17	3	1.17
Precision/Reliability	0.26	3	0.78	3	0.78	2	0.52
Cost	0.16	2	0.32	3	0.48	1	0.16
Ease of Implementation	0.11	2	0.22	2	0.22	1	0.11
Durability	0.08	3	0.24	3	0.24	2	0.16
Total Weighted Score		**2.34**		**2.89**		**2.12**	
Ranking		**2**		**1**		**3**	
Continue?		NO		**YES**		NO	

Figure 5. Concept Selection Matrix

As shown by the concept selection matrix (Figure 5), Concept 4, the single trip laser, scored the highest and was chosen for further development. We chose Concept 4 as our preferred concept due to its excellent accuracy, precision, cost effectiveness, and durability. Of all eight concepts initially developed, Concept 4 proved to be the best as demonstrated by the concept generation, development, and selection phases of the engineering design process.

The iGen4 Paper Velocity Measurement Device

Our design concept can be generalized as a system that utilizes a vertical trip laser, located in a horizontal paper path of the iGen4 printer, to measure the amount of time it takes for a sheet of paper to move through its beam path. To find the velocity from this time measurement, the distance the paper travels, which is equal to its length, is divided by the time measurement ($\frac{Distance}{Time}$). This then produces an average, actual velocity measurement of the entire piece of paper, expressed in distance units per time unit, or millimeters per second.

For example, if a 150mm long sheet of paper breaks the path of the laser beam for 3 seconds, its velocity can be expressed as $\frac{150\ mm}{3\ seconds}$ or 50mm/s.

Our paper velocity measurement device consists of six total components, three of which are already located on a simple horizontal paper path. These six components are: the paper path housing, drive rolls, baffles, the laser housing, the laser itself, and the laser receiver. In a standard horizontal paper path, the paper path housing already holds drive rolls and baffles. These are responsible for pushing the paper in a specific direction as well as functioning as a stabilizer of the paper. Figure 6 shows a schematic of all the major components of our design solution.

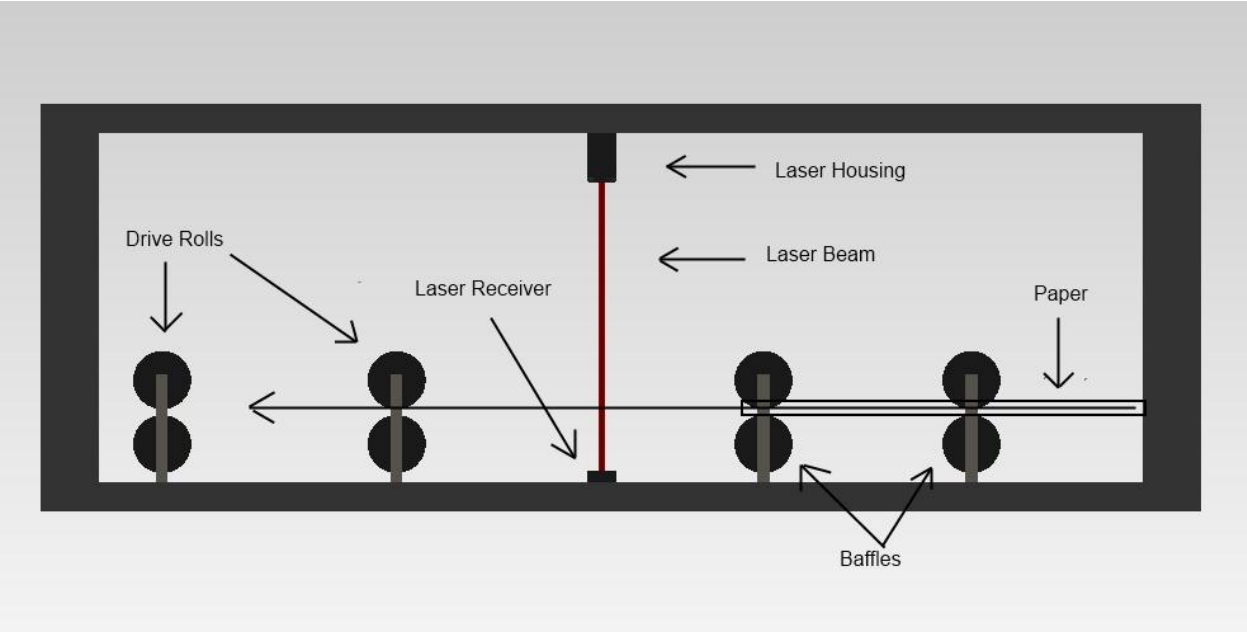


Figure 6. Schematic Drawing of Our Device

Each component of our device has a specific function in the paper velocity measurement system. The drive rolls function to push the paper forward in a simple horizontal paper path. The paper is supported by the baffles, located directly below the drive rolls. The laser housing contains the laser beam diode that emits a red trip laser beam directly downwards. This laser meets the laser receiver component, which functions to identify if the laser beam's path is broken or not, control the timer, and measure the time elapsed when the laser beam's path is broken. These components all function together to measure the actual velocity of a sheet of paper as it moves through any simple horizontal paper path. Overall, our design is extremely simple.

One of the greatest aspects of our design is its ease of implementation into a Xerox copying system, such as the iGen4 printer. Figure 7 shows a sectioned cutaway of the iGen4 printer. The paper paths visible in this cutaway are highly ideal for the implementation of our

device due to their simple horizontal alignment. Multiple horizontal paper paths are visible in Figure 7.

Figure 7. A Cutaway of the iGen4

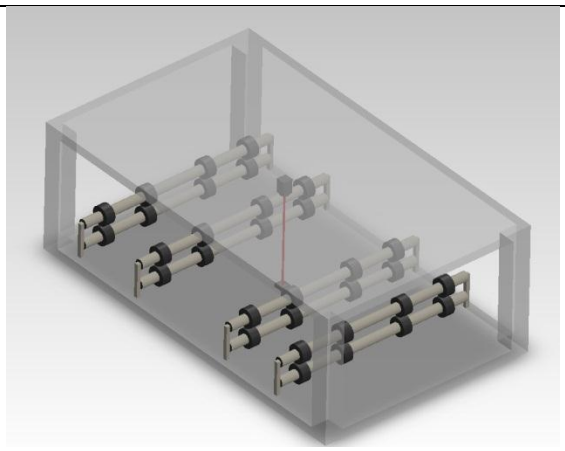
Our device could be incorporated into any horizontal simple paper paths in the iGen4 printer. This is very cost effective as well because it does not require the creation of any new paper paths! Our device is simply an add-on to the iGen4 that will further increase its accuracy, reliability, and alignment.

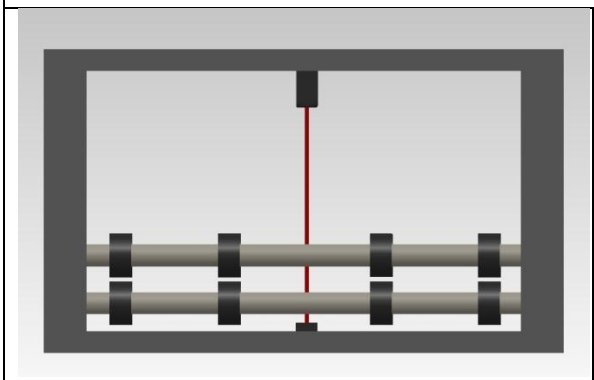
In addition to the previously described ease of implementation of our design, it also has many other significant elements that further add to its value. Our device excels at meeting the customer needs we identified, as shown in Figure 5. Due to the nature of light itself, our device is accurate to the speed of light! The moment that the path of the laser is broken by the paper is immediately identified by the laser receiver because no more light is striking it. After the last tiny bit of paper travels through the laser beam, the laser's path is immediately restored at the speed of light as the laser travels back down and strikes the receiver. This causes virtually no time to elapse between the clearance of the paper through the laser and the restoration of the

laser's path. Therefore, our device is accurate to the speed of light! The precision and reliability of our device is also notable. Since the laser beam is powered by electricity, it will never change or travel any slower, ensuring a consistent method of time measurement. Also, our device is super reliable because it will constantly function and never turn off. Xerox can count on our device never ceasing to execute its function. In addition, our device can also measure the velocity of different sizes of paper; it is not limited to only standard paper. No matter the size of the paper, it still must travel through the same laser beam, ensuring a reliable measurement. Overall, our concept goes above and beyond in satisfying all of the needs, requirements, and specifications presented by Xerox.

Another important element of our design is its independence from all other variables presented by the paper stock moving through the paper path. The paper thickness, finish, and size can all vary, but the measurement of the paper's velocity is completely independent from these variables. Our device also does not measure the velocity of the drive rolls nor depend on them; rather, it measures the velocity of the paper itself, which is much more accurate.

Our team did a terrific job creating CAD models of our design concept in Solidworks. Creating these CAD models allowed us to design three-dimensional models that fit our specifications as well as explore and understand our concept even more. In addition, these models allow us to neatly communicate our design in a format that is accurate and to scale. Table 2 shows trimetric, front, and isometric views of our CAD model.





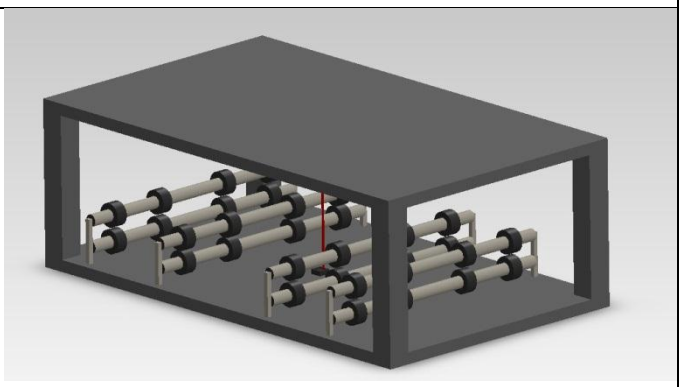


Table 2. CAD Model Views

A step-by-step procedure of our device consists of roughly eleven steps. First, a piece of paper moves horizontally through a paper path, pushed along on baffles by drive rolls. When the paper breaks the path of the laser beam that originates from the laser housing and connects to the laser receiver, the laser receiver triggers a timer to start. The paper moves along through, still breaking the path of the laser. As soon as the paper fully moves through the laser and its path is restored, the receiver stops the timer and records the amount of time it took for the paper to move through the laser. Utilizing this time measurement and the distance the paper traveled, which is its predetermined length, the computer system of the iGen4 can then calculate the velocity of the paper. The distance the paper traveled, or its length, is divided

by the amount of time it took to travel this distance to calculate a rate of distance/time, or velocity at which the paper is traveling. The iGen4 then utilizes this velocity and makes any necessary adjustments to its printing process to ensure an accurate printing job.

Perhaps the most appealing aspect of our design is its low cost and excellent cost effectiveness. Due to the simplicity of our design, only two parts are required to be implemented. The laser housing, containing a laser diode, and the laser receiver, must be manufactured and implemented into the iGen4. It is estimated that the laser housing/diode will cost roughly $100 for a high quality laser. Also, it is estimated that the laser receiver will cost roughly $80 for a small, high quality receiver. This adds up to a total first cost of $180 for the parts to our design. Since our device is extremely simple to implement, requiring only placement of the parts on the paper path and connection to the electrical wiring and computer of the iGen4, the operating cost of implementing one of our devices would be roughly $70 per hour of labor. It is estimated that this device would take around 1.5 hours to implement and align, creating a total labor/operating cost of $105. Since our device requires no maintenance, there will be no maintenance costs required in the future. Adding together the first cost of parts to the operating cost of implementation and labor creates a total cost of roughly $285. This means that it will cost an iGen4 owner or Xerox $285 per device they add on to each iGen4. This cost is extremely low, especially compared to the cost of the iGen4 itself, which exceeds $1 million. $285 is a tiny fraction of the cost of one iGen4 printer, yet the quality it ensures exceeds the value of its tiny cost, characterizing our design as extraordinarily cost effective.

Conclusion

When tasked with creating a paper velocity measurement device for Xerox's iGen4 printing system, our team designed a device that excels in satisfying the needs and specifications of Xerox as well as ingeniously succeeds in completing its function. Our device consists of a vertical laser beam located on a horizontal paper path. This beam is broken by the paper for some amount of time. This amount of time is recorded in addition to the distance the paper traveled, or its length. The length of the paper, or distance, is then divided by the time measurement, producing a rate of distance/time, or velocity. This is an actual velocity measurement of the paper and is accurate to the speed of light! In addition to our design's accuracy, functionality, and reliability, it also happens to be extremely cost effective, having a total cost of $285. This small cost is exceeded greatly by the benefits and quality that our paper velocity measurement device provides to the iGen4 printing process as well as to Xerox.

Overall, our team had a very enlightening experience with this design project. This project opened our eyes to the reality that we had to meet together and really work as a team multiple times. We also learned that we had to be good communicators in order to function efficiently. In regards to design principles, our design goes to show that sometimes the most comprehensive solution is not necessary for a problem! We created a very simple solution that gets the job done well and is also cost effective. Finally, we also learned of the importance of keeping detailed records of all activities and creations. This made it much easier to create a high quality oral presentation as well as a high quality written report. Of course, any idea is useless if

you can’t communicate it, therefore we also learned of the importance of communicating our ideas effectively!

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