RECOR-DIY

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ABSTRACT

RecorDIY is an affordable alternative to ordering Vinyl Records from a manufacturer in the form of an at-home record-cutting lathe. This report will cover the record cutting process from audio to physical, at home record lathes that are currently available, and the possible improvements that I plan to implement in order to make these devices a more viable alternative for small artists. Current models can only create low fidelity records, specifically they struggle with lots of "noise", extra sounds such as static that make it harder to hear the actual audio. Another issue is record size, as current models can only fit about only fit about 4 minutes of music per side on a 5-inch disc. The last issue is price, currently in order to acquire a lathe that can cut records even close to the quality you would expect from a record that is viable to be sold to consumers can cost upwards of $30,000. When considering the possible solutions for these issues there are 2 main components that will serve to best rectify these issues. The design of the lathe cutting head, and the material used for the vinyl records. The Lathe cutting head can be made in either a "monophonic" or a "stereophonic" configuration, the monophonic configuration is a much more straightforward method of engraving the record, which can lead to a superior fidelity as a result, however this method sacrifices some of the dynamics of a track as it removes the "panning" of a song. The Stereo Configuration is a much more complex head, which requires a much more precise construction as well as execution, which often means that lots more tweaking is necessary in order to ensure a quality cut, in exchange for this extra effort and precision, the artist is rewarded with a much more dynamic and full sound. The records themselves can be made from either polyvinyl or polycarbonate. Polyvinyl is the typical medium for batch-pressed records as it is a much softer and malleable material, but it is also a viable option for lathe cutting as well. Due to its malleability polyvinyl must be cut much more precisely to avoid adding excess "noise" to the recordings, but it is also capable of achieving a higher fidelity through these means. Polyvinyl is also more expensive than its polycarbonate counterpart as it is in high demand due to its use in vinyl pressing. Polycarbonate is the cheaper alternative to polyvinyl, a slightly tougher material, but typically the material of choice for lathe cut records, under the right circumstances can achieve a comparable fidelity to its polyvinyl counterpart, however it is not quite the same. To make the device as user-friendly as possible, as well as reduce costs, my research indicates that the best solutions moving forward will be to use polycarbonate discs up to 10 inches in diameter [roughly 9-12minutes per side], in combination with a monophonic head for ease of use and more consistent high-fidelity sound.

Problem Statement:

The Goal of this project is to make improvements upon currently available designs for at home record engravement in order to improve its overall quality of cut and create a viable alternative to ordering batch-pressed records.

The Gakken Toy Record Maker Kit is currently one of the only cheaply and easily available forms of a cutting lathe in the market (although it is currently only available in Japan). The kit comes with everything you need to assemble the machine, as well as materials to cut a few mini records of your own. The drawbacks to this machine come from the miniscule size of the disks, as well as the lack of precision control over the weight, speed, and fidelity of the cutting process. The mini records that this machine produces are approximately 5 inches in diameter, and capable of recording up to about 4 minutes of uninterrupted playtime per side. These records are playable on normal record player as well, however any automated player will find them too small to play. The machine comes with 2 arms, an arm for cutting, and an arm for playback, as well as auxiliary inputs and outputs. The cutting arm utilizes a monophonic cutting head, and its weight distribution is controlled by an adjustable spring mechanism. The monophonic cutting head supplied in the kit utilizes a simplistic design, however the issue with the head comes from the quality of the driver which supplies the vibrations to the cutting needle. In order to keep costs low, it is safe to assume that the head supplied with the kit uses a cheap driver, not suited for high fidelity record cutting. Meanwhile, the spring mechanism works in a functional capacity, but the mechanism and the method of control both lack any serious precision or consistency. The blank records and the cutting arm are both powered by a single DC motor in located in the main body of the device. The single motor can power both of these in parallel by using a series of belts and gears which allow the cutting arm to slowly push inward in time with the record to keep a consistent spiral. However, this streamlined design is not without drawbacks, as unfortunately when the needle cuts into the vinyl, it produces a non-negligible amount of friction that the motor is not powerful enough to overcome completely. This can cause the record to have a varying speed upon playback. The result of all this lack of precision is a very sloppy, noisy record, the loudest sounds that these records make by far is unfortunately the excess background noise. The song itself ends up being quite quiet in comparison, as any attempts to increase the volume can lead to needle, “jumping” or just a general degradation of the sound quality. To hear the song that has been recorded, requires listening “through” the noise to hear the songs, and as such, these records are in no way shape or form fit for sale to consumers.

Literature Review:

The modern age of music has made the industry all at once the most accessible it has ever been with the growth of streaming services, and the availability of at home recording software. However, at the same time it remains one of the hardest industries to “break into” and really make a career out of due in large part to the existing structures of power that control the money in the industry. Without the large audiences afforded to bigger artists, or the support of any sort of label, it is often very difficult to grow a sustainable audience size, and even harder to monetize that support in order to make a career in music. (Output, 2021) Streaming services pay fractions of a cent per stream, gigs can be few and far between, and even when touring, the costs of travel and daily operations eat up most of the profit. (Hunter-Tilney, 2022) The real money in both industries is in the merch. Physical merchandise is by far the best method that artists of all sizes

can utilize to monetize their audience. There are many creative and novel ways to produce merchandise for your audience, however the most common are stickers, apparel, and physical copies of the band's music. While large artists with label backing can utilize all these avenues to the fullest, without significant capital smaller/DIY artists must be much more selective of the mediums they choose when investing in merchandise. One area of merchandise that smaller artists have had a particularly hard time breaking into is vinyl. The current market for vinyl records has exploded within the past 2 years, growing “a whopping 61%” in album sales revenue in just 2021 alone. “In the first six months of this year, 17 million vinyl records were sold in the United States, generating $467 million in retail revenue, nearly double the amount from the same period in 2020, according to the Recording Industry Association of America.” (Industrial Media, 2022) This rapid growth has outpaced growth rates even for streaming giants like Spotify, which makes the vinyl market an exceptionally lucrative market.

The unexpected revival of the vinyl industry did not come without its drawbacks; however, as the world shifted from analog to digital, the music industry did the same and as a result, most of the hardware required to manufacture vinyl records was disposed of. (Sisario, 2021) The impact of this is felt today as the gutted industry struggles to keep up with the renewed demand for vinyl records. Creating new plants is a challenge in and of itself as the only manufacturers of the machinery required for production are located overseas, “New machines came along only in recent years, and can cost up to $300,000 each. There’s a backlog of orders for those, too.”. (Industrial Media, 2022) Supply chain issues with raw materials, “including vinyl polymers, have caused problems too.” (Eggertsen, 2022) Both black compound [PVC] and Nickel, a vital element in vinyl record production, are in high demand and short supply. With backlogs as long as 8 months, lack of manufacturing facilities isn’t the only thing standing in the way of vinyl’s big comeback. The retail cost of vinyl has increased due in large part not just to the shortage but increases in labor costs and raw materials as well. The turnaround time for vinyl records also poses a significant threat to revenue streams for artists as any well performing record will often go months without being on shelves due to the long production time and significant backlogging. This backlogging can be a major issue for small artists, as timing is everything when it comes to launching new music. If an artist finishes their album in January for example, and they must wait until September to receive their records, they are forced to either delay the album ⅔ of a year, and the entire campaign that comes with it, as well as their tour presumably, all in order to ensure that the product they have purchased will even sell. Unless they want to take the significant risk that their new album will still be in high demand 8 months after its release, and they won't have just purchased a now irrelevant product. While this may be doable for big name artists signed to large record labels, for smaller independent artists, these circumstances can almost completely block them out of the market, “Vinyl production’s a volume game… It inadvertently hurts independents more than majors because majors can guarantee a higher volume.” (Eggertsen, 2022)

There are 2 main ways that records are produced; engraving or pressing. While the initial steps happen to be practically identical, the most utilized method, pressing, is quite a bit more involved than its counterpart. The first step in pressing a vinyl record is to make a “master disc” which will essentially act as the benchmark for what the record should sound like as well as the base that next steps will be built upon. A Master Disc is made with an aluminum core coated in lacquer. This lacquer disc is then carved by a machine called a “lathe cutting machine” which

uses a microscopic sapphire tipped stylus to transcribe the music into grooves that can be read by a record player. Once the engineer is satisfied with the transcription, the master disc is sprayed with liquid silver, washed to remove any excess, and then sprayed with tin chloride to harden the master disc. Once the Disc has been hardened, it is put through an electroplating process during which nickel is bound to the silver coated disc. Once this has been achieved, the press is prepared for use by making room for the center hole and label. Once in use, the press works by applying intense heat and pressure to small vinyl "biscuits" (small rounds of polyvinyl) which press the grooves into the material before they are trimmed to remove excess material and allowed to cool to avoid warping. (Henshall, 2022)

Lathe cut records, unlike batch press records, only really require a lathe cutting machine, as the records are recorded (engraved) into the disc in real time and then ready for release. Lathe Cut records are typically cut out of polycarbonate discs, as opposed to polyvinyl discs. (Hill, 2022) The largest downside is that since the records are cut in real time, the longer the record, the slower the production rate, as the lathe must cut the entire length of the project every time, as opposed to just once for press batches.

Solution Design:

There are four main areas of issue that would most benefit the machine if redesigned with small scale production in mind. These areas are disk size and scale, cutting head composition, overall precision of controls, and lack of power from the motor. Solving an issue like a limitation on disk size is an uncomplicated issue to tackle as luckily the solution is as simple and obvious as simply increasing the scale of the machine. The Gakken Toy Record Maker has a turntable that is 4 inches in diameter, and simply increasing the size of the turntable to accommodate 10 in disks would almost certainly solve this issue immediately, however this problem, much like the others are intrinsically linked to one another, as the increased weight of a larger disk will require a stronger motor to maintain the necessary speeds, on top of the already underpowered motor that the machine currently contains. The cutting head composition itself presents little issue in the way of design and is limited mainly by the hardware supplied for its construction in its current state. Simply replacing the supplied driver in an identical orientation with a higher quality driver would yield immediate improvements in the fidelity of the cuts from the machine. The most difficult issue to address by far is the precision controls required to truly allow the artist to properly adjust the machine to produce the best sounding translation of their music onto vinyl. Being able to properly regulate speed, needle pressure, and speaker volume could be best accomplished a couple of ways. Adding a digital display that shows the user the measurements of each of those three metrics would allow for an incredibly precise and easy to read recording experience. Another option could be to simply to increase the size of the knobs in order to better mark along the circumference the level lines ranging from min to max of each metric. While improving the volume and speed controls sensitivity can be broken down to simply upgrading components, managing the needle pressure represents an entirely new challenge as the mechanism itself is largely at fault for the inaccuracy. This can be circumvented by adding a pressure sensor into the spring mechanism in order to properly gauge the resistance the spring applies to the cutting arm, or possibly replacing the spring entirely with an electronic piston instead.

Evaluation of Proposed Solutions:

In evaluating the new design for an affordable record lathe, various factors that influenced the decision-making process had to be considered. There were three main limitations: time, expertise, and economics. These constraints helped to focus efforts on addressing specific issues that could be tackled directly within the given limitations.

One of the challenges tackled was determining the optimal size for the cuttable discs. Considering the constraints of the available materials and resources, as well as the desires of the intended consumer base, narrowed the choices down to a 7-10.5-disc size range. The next aspect of the final design that received attention was the cutterhead. Different options were explored, and modifications were made to enhance its performance within the constraints. However, this involved optimizing the shape and material, rather than the cutting mechanism of the cutter head, as the expertise or resources necessary to ensure precise and high-quality cuts on the record discs were beyond the scale of this project.

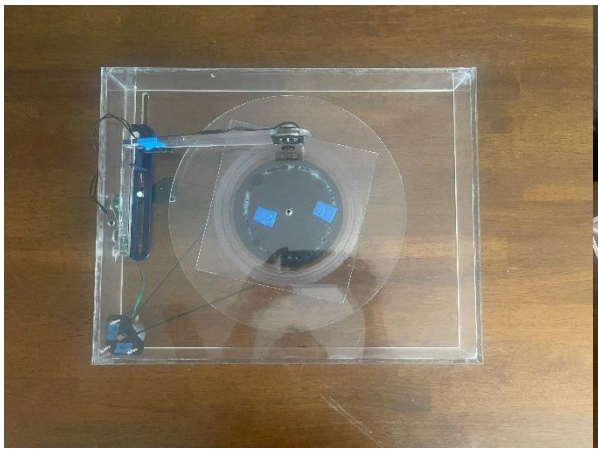

Figure 1: Initial Prototype Design

Figure 2: Initial Prototype Design

The Motor was not hard to replace as research revealed that a majority of belt driven turntables use identical motors, so all that was necessary was to swap out the low powered motor for a stronger one. In terms of materials, laser-cut clear acrylic was utilized for the body and cutting arm of the new design. This choice was driven by factors such as affordability, ease of manufacturing, and the ability to showcase the internal components through transparency. Laser cutting allowed me to shape the acrylic precisely and consistently, ensuring the desired dimensions and aesthetics. For the arm mechanism, 3D printing was used. This technology offered flexibility in designing complex shapes and allowed for quick iterations during the prototyping stage. This was sorely required as ensuring the proper dimensions of the teeth took 5 iterations and hours of post-processing.

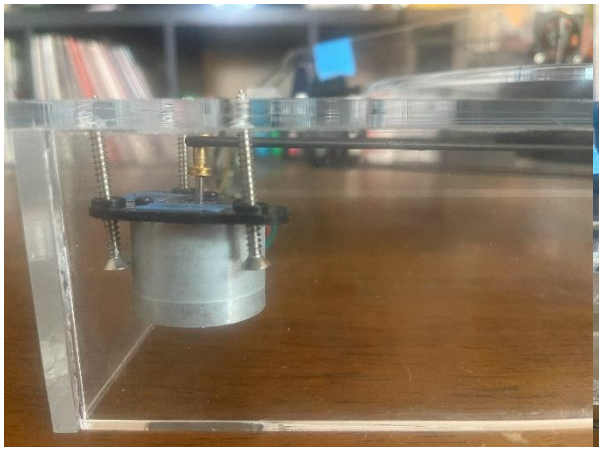

Figure 3: Turntable Motor

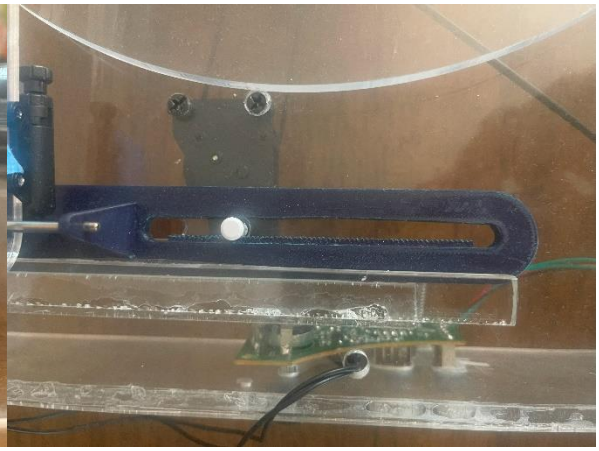

Figure 3: 3D-printed Arm Mechanism

To keep costs low, as previously stated, parts were repurposed from an old turntable and from the original Gakken Toy Record Maker. This approach allowed existing components to be utilized as either final or temporary substitutes for higher quality parts in future iterations. By repurposing these parts, the overall cost of the new record lathe was successfully reduced, while benefiting from the performance and reliability of the salvaged components. In total, the parts used in creating this new design amounted to approximately $130. This is thanks to a conscious effort to develop an affordable solution within the budget limitations, which hopefully will pass savings onto the consumer. By carefully selecting materials, repurposing existing components, and employing cost-effective manufacturing methods, the consumers are provided an accessible record lathe option for a broader audience.

Figure 4: control unit from Gakken

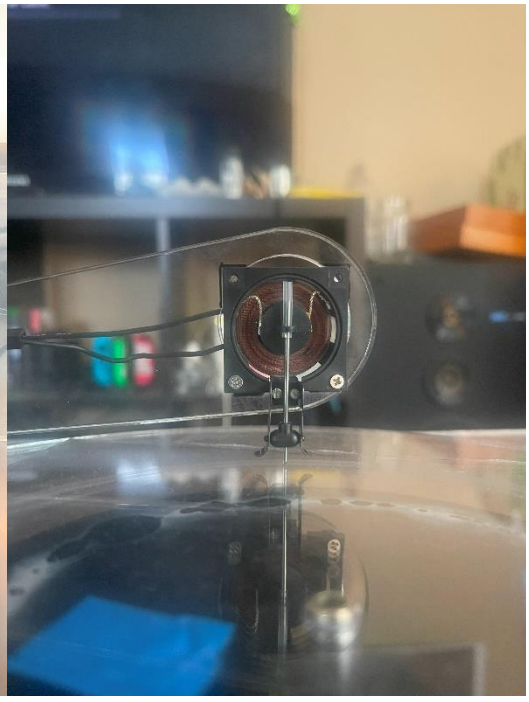

Figure 5: Driver and needle from Gakken

Upon the device's immediate completion, multiple test cuts were made, to disappointing results, however, after some fine tuning, the lathe was able to produce a few passable recordings. These cuts, however, are far from the desired outcome, as the sound is buried beneath a very large amount of noise. Several factors could potentially contribute to the low-quality sound of the recordings as Record lathes require a great deal of precision, however, several key factors that are specifically affecting the quality of the cuts that can be produced have been identified:

1. Dull Carving Needle: One significant factor impacting the recording quality is the condition of the carving needle. If it is dull or worn out, it will struggle to accurately cut the grooves, leading to a loss of fidelity and increased background noise. Addressing this issue by replacing the needle of a higher quality, such as a ruby or sapphire tipped needle rather than tungsten could increase the fidelity of the cuts by a significant margin, but this would drive up the cost as well as they can cost upwards of $200 a needle.

2. Insufficient Volume Allowance: With the current construction, the driver that is being used to translate the vibrations to the carving needle is too weak to handle many of the desired frequencies at an appropriate volume. Replacing this driver, similarly to the needle, could vastly improve the quality of the cuts, however it will also lead to increased material costs.

3. Improperly Mixed Audio: The fidelity of the recordings can also be impacted by the audio itself. If the audio being fed into the lathe is not properly mixed or balanced, it can result in suboptimal sound quality and increased noise. Ensuring that the audio is properly mixed for cutting will lead to a much more desirable outcome.
4. Lathe Arm Instability: The stability of the lathe arm during the cutting process plays a vital role in the quality of the recordings. If the arm is prone to vibrations or lacks stability, it can introduce unwanted noise into the cuts. Strengthening the arm mechanism to improve stability would likely yield better results.

5. Crooked Turntable: The turntable itself may contribute to the noise issues if it is slightly crooked or exhibits any wobbling. Even a small amount of instability can result in irregular grooves and increased background noise, as well as audio distortion, a "wobbling" in the pitch of the recording. Ensuring that the turntable is properly aligned and addressing any instability issues would help mitigate this problem.

Identifying these factors helps provide a plan for improving the design and addressing the specific issues that are impacting the quality of the recordings. By addressing the dull carving needle, increasing the volume allowance, ensuring proper audio mixing, improving the stability of the lathe arm, and rectifying any turntable misalignment or wobbling, the overall sound quality can be significantly enhanced and reduce the excessive noise in the recordings. Through these refinements, the desired outcome of producing quality recordings with a more acceptable fidelity and minimal background noise for consumers to enjoy can be achieved.

Verification and Validation of Proposed Solutions:

There were three main key performance indicators measured in order to judge the quality of this next generation of record lathe: Disc Size, Fidelity, and Affordability. These indicators played a crucial role in evaluating the effectiveness and viability of the prototype.

In terms of Disc Size, achieving the goal of a 10" disc was a significant accomplishment. The machine was designed to track and carve recorded audio from the edge of the disc up to approximately 2" from the center. This size limitation aligns with the industry standard, as the label on the center typically occupies that space. Meeting this objective ensures compatibility with existing vinyl formats and allows artists to produce records that would be compatible with most turntables.

Maintaining Affordability was another important consideration throughout the development process. The aim was to keep the retail price of the machine below $600. Fortunately, this goal was within reach, as the project's current scale prevented the expenditure of funds on materials that could potentially drive up the cost. With the total material expenses amounting to approximately $130 and considering construction and machining time, the estimated production cost of the prototype was around $418. Even with a final price point of $600, there remained a comfortable profit margin of around 30%.

However, the most challenging and critical key performance indicator was the fidelity of the cuts. Enhancing audio quality was of utmost importance, with specific goals set for reducing noise by 60%, improving clarity by 25%, and eliminating the effects of needle friction. To test these parameters, numerous test pressings were made, each involving alterations in various contributing factors. Adjustments were made to the needle pressure, media volume, cutting material, and audio mixing in the pursuit of optimal results. Given the expense of cutting materials, each test cut was limited to a duration of 5-10 seconds.

After refining the cutter's settings, a full track was cut to evaluate the overall outcome. Unfortunately, the prototype fell short of meeting the proposed goals. The noise reduction, clarity improvement, and mitigation of needle friction showed minimal, if any, advancements with the new medium and mechanism. Consequently, while the device successfully expanded its capabilities significantly, its current state does not produce a product of the necessary quality to be sold to consumers.

Addressing the fidelity issues will be critical to the success and market acceptance of the affordable record lathe. Further research and development efforts are needed to identify and rectify the limitations that hinder the desired improvements in audio quality. Overcoming these obstacles would allow the machine to offer a viable solution for artists seeking to cut their own high-quality vinyl records at an affordable price, potentially revolutionizing the accessibility and creative freedom within the vinyl industry.

Impact Analysis of Proposed Solutions:

For the vinyl record industry, the introduction of an affordable lathe would likely disrupt the traditional model of record production and distribution. Currently, small artists often face significant financial barriers when it comes to releasing physical versions of their music, especially on vinyl. They typically have to rely on record pressing plants that have high minimum order quantities, which can be far too expensive for independent artists with limited budgets. As a result, many artists opt for digital distribution or limited cassette/CD runs instead of vinyl.

With the availability of an affordable lathe however, artists would gain the ability to cut their own vinyl records at a fraction of the cost. This would lower the financial entry barrier for artists looking to release their music on vinyl and could lead to an increase in the overall number of vinyl releases. The vinyl record industry could experience a surge in demand as more artists, especially those in niche or independent genres, seize the opportunity to produce physical records. This increased demand could potentially stimulate growth in vinyl sales, benefiting pressing plants, vinyl suppliers, and other industry stakeholders.

Artists could also experiment with customization and limited editions. They could create unique vinyl releases with personalized artwork, special colors, or even exclusive messages etched into the record. Such special editions often command higher prices and attract collectors and dedicated fans who value these unique and limited offerings. This could result in increased revenue streams for both the artists and the industry as a whole. By cutting their own vinyl records, artists would eliminate the need to rely solely on pressing plants, which are far more expensive, and have much longer wait times. They would have greater control over the production process and could reduce their upfront expenses by producing records on-demand or in smaller quantities. This flexibility would be especially good for emerging artists or those with smaller fan bases.

Additionally, cutting out the middleman and producing their own records would allow artists to capture a larger share of the revenue from their vinyl releases. Currently, artists receive a percentage of sales from record labels or distributors, but it is often a smaller fraction compared to the costs involved. By cutting their own records, artists could potentially earn higher profit margins on each sale, increasing their overall income and financial independence.

Implementation Plan:

Looking into the future, once the design phase has been completed and the key performance indicators (KPIs) have been successfully met, the focus will shift towards manufacturing, distribution, and marketing of the product. With its target audience being a more niche and specific demographic, it becomes crucial to devise a grassroots marketing campaign that can have a significant impact on the larger scene. The aim is to generate awareness about the new product through effective word-of-mouth strategies and by leveraging social media platforms like TikTok, which have proven to be highly influential among the DIY community. By strategically spreading the word and showcasing the affordability and value of this alternative to

traditional record pressings, the product is expected to quickly gain traction within the target market.

Given the anticipated demand for such a product, it would be wise to establish a partnership with a larger manufacturer that possesses the capabilities to meet the expected demand. The current assembly process may not be refined enough for mass production, hence the need for a collaboration that can ensure efficient and timely manufacturing of the device. Fortunately, the simplicity of the product's design lends itself well to quicker and easier mass production once the necessary adjustments are made. To maintain the product's quality, there will be a segment of the manufacturing process that requires additional investment due to the precise nature of the components being produced. While this might increase costs, it is necessary to maintain the product's standards. However, the expenses associated with these precision components will be offset by the cost savings achieved through utilizing cheaper manufacturing processes for the simpler portions of the product, which make up the majority of its composition.

Conclusion:

To summarize, the RecorDIY project aims to provide an affordable alternative to ordering vinyl records from manufacturers by developing an at-home record-cutting lathe. The current models available in the market suffer from limitations such as low fidelity, limited record size, and high cost. To address these issues, the project focuses on two main components: the design of the lathe cutting head and the material used for the vinyl records.

The project proposes using polycarbonate discs up to 10 inches in diameter, which can accommodate approximately 9-12 minutes of music per side. Polycarbonate is a cost-effective alternative to polyvinyl and, under the right circumstances, can achieve comparable fidelity. By using polycarbonate and a monophonic head, the project aims to make the device more user-friendly and reduce costs. As well as other design improvements, such as increasing the size of the turntable to accommodate larger discs, upgrading the driver for the cutting head to improve fidelity, and enhancing precision controls for regulating speed, needle pressure, and speaker volume.

While there are limitations due to time, expertise, and economics, the proposed solutions provide feasible improvements within these constraints. The evaluation of the design choices, such as the disc size, cutterhead modifications, and material selection, was driven by considerations of affordability, performance, and ease of manufacturing. However, by addressing these issues and implementing the proposed solutions, the RecorDIY project aims to enhance the overall quality of cut and create a viable alternative for small artists to produce their own vinyl records at home. This project has the potential to empower independent musicians, provide them with a tangible and marketable product, and tap into the growing demand for vinyl records in the music industry.

References

Eggertsen, C. (2022, June 4). Will Price Hikes Scratch Vinyl? 1. New York. Retrieved from Billboard.

Henshall, M. (2022, January 19). *How Are Vinyl Records Made?* Retrieved from Your Sound Matters: https://www.yoursoundmatters.com/vinyl-records-made/

Hill, J. P. (2022, May 25). *You should produce your vinyl records via short-run lathe cutting - here's why.* Retrieved from DJ Tech Tools: https://djtechtools.com/2022/05/25/you-should-produce-your-vinyl-records-via-short-run-lathe-cutting-heres-why/

Hunter-Tilney, L. (2022, May 18). How do today's musicians make money? London.

Industrial Media. (2022, June 28). Manufacturers Struggle to Keep Pace with Vinyl Record Demand. Madison. Retrieved from Manufacturing.net.

Output. (2021). How Much Do Musicians Actually Earn?

Sisario, B. (2021, October 21). Vinyl Is Selling So Well That It's Getting Hard to Sell Vinyl. *The New York Times*.