Turbine Integrated Pitching System
Scope of Work

Team F96
TIPSY

Members:
Elizabeth Costley
ecostley@calpoly.edu
Cameron Jackson
cjacks28@calpoly.edu
Jeff Larson
jlarso18@calpoly.edu
Josephine Maiorano
jmaioran@calpoly.edu

Sponsor:
Cal Poly Wind Power

Mechanical Engineering Department
California Polytechnic State University
San Luis Obispo
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Abstract

The Cal Poly Wind Power club has requested a mechanism to pitch the blades of its small scale wind turbine for the Collegiate Wind Competition. Research was performed in journals, patents, and studies regarding the stakeholders and needs, existing products and solutions, and technical challenges involved in order to evaluate the potential ways to approach the problem. The customer's requirements were evaluated and shaped into engineering specifications in order to fully define the problem and the team's approach to solve it.

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Introduction

The Turbine Integrated Pitching System (TIPSY) senior project has been tasked with designing and building a small scale blade pitching system for Cal Poly Wind Power's, hereafter referred to as CPWP, competition scale turbine. The function of the pitching mechanism is to hold and provide rotational motion control to the turbine blades in order to optimize energy capture at different wind speeds. CPWP is competing in the Collegiate Wind Competition, hereafter referred to as the CWC, in June against schools from all over the country. The TIPSY senior project will be working hand in hand with CPWP and the club leads will act as the primary sponsors for the project. The senior project is closely integrated with the rest of the turbine, as such, transparency and collaboration regarding engineering design will be critical for the success of the project. To aid in defining the specific design requirements, the CWC has a layed out a set of rules [1] for all of the competition teams to follow. By the nature of the competition our design is set to be as light as possible, while still maintaining structural integrity and accurate blade rotation. Our team will build a physical mechanism while the club will be providing the mechatronic controls for the project.

This report will provide preliminary information on the scope of work that will be required to design, build, and test our project. It will first discuss the background research that will go into choosing the best solution to our problem. Our research includes patents, articles, previous designs to similar problems. Next we will discuss the project scope and define the goals and scope of the project. Then it will look into the objectives of the project and define the problem and specific design specifications needed to satisfy CPWP. It will then move on to explain our methodology to project management and what will need to happen to ensure goals are met on time and with high quality. Finally the appendix will include a house of quality, functional decomposition, and a gantt chart.

Background

After the problem was defined and initial brainstorming had occurred, a list of possible solutions was compiled. In this section of our scope of work, each possible solution will be discussed.

Stakeholders and Needs

The stakeholders for this project are easily identified as the CPWP team, and the CWC. To gather information about our stakeholders, interviews were conducted with several CPWP leads (including the team lead, power lead, drivetrain and structures lead, and blades lead). These interviews were used to define the needs of the project and to inform the direction of the design. The CWC rules [1] were also carefully read to identify the overall objective of the turbine design, as well as specific requirements pertaining to the pitching mechanism. More detailed project requirements can be found in our objective, but some notable takeaways from these interview include the need for durability within the design. Additionally the importance of a circular shaped blade root connection to improve blade strength, as well as the importance of small hub diameter and limited axial space due to competition size constraints. The need to minimize power draw was also highlighted, including ensuring components will use less than 9V combined. Some of the limitations of these interactions is that without knowing the details of the pitching mechanism final design, the interface with the other portions of the turbine are not fully understood and the project team will maintain regular contact with CPWP as the design becomes refined.

Existing Products and Solutions

Previous CWC Teams

One source for information on existing products and solutions are the designs from previous teams that competed in the Collegiate Wind Competition. The turbine design reports are available through the competition website, as well as how this team placed in the competition. These reports are especially useful because they were designed for very similar constraints as our turbine. The pitching mechanisms from these teams all used electric motors as linear actuators, and an arm linkage solution to pitch the blades [2,3,4,5,6]. There were many variations in terms of the geometries used. One such variation includes using a curved arm in the linkage to provide a larger range of pitch angles while occupying less space [2]. To create the hub several teams also utilized/modified existing hubs from RC helicopters, specifically the JCZK 300C [5] and Align 700 [6]. They also utilize a swashplate-style push plate to convert the linear actuation from the stationary part of the turbine to the rotating blades/shaft. Some of the limitations of these sources is that they provide a summary of the design but do not go into full detail about the design. Furthermore, they do not provide any specifics about the performance of the pitching mechanisms, their power draw, or the results of any testing.

Other Small Scale Turbines

There are also research papers available on the design and control systems for small scale wind turbines. One of these outlines the principles for how a pitching system with a slider arm functions [7]. This system includes a stepper motor with a slider that connects via arms to the blade mountings to pitch them. This particular design provided a 30 degree pitching range for a turbine with a rotor diameter of .58 m. Other papers provide background for how to develop a control system for the pitching mechanism. This includes collecting information on windspeed optimal pitch angle, rotational speed and output voltage. Using this information and Simulink models, one can develop an algorithm for pitching the blades based on output voltage, which can be implemented using a microcontroller [8]. A limitation of these sources is that they do not operate under the same limitations as the competition turbine, especially when related to all power for the pitching mechanism needing to be produced by the turbine, with minimal opportunity for onboard storage.

Commercial Turbines

Information on how commercial, utility-scale turbines were found through research papers and other website resources. Commercial turbines utilize a separate motor to pitch each blade, which driver a larger ring gear that is connected to the blades [9]. These motors are usually brushless motors and have a battery or ultra capacitor as backup to allow for control of the pitching when the turbine is not actively producing power [10]. Unfortunately, this design is not as applicable to our turbine because we do not have the space for separate motors for each blade, and no not need as much power to pitch our blades (due to their much smaller size) and thus do not need an individual motor per blade. Furthermore, there is a maximum of 10 joules of energy that can be stored in the turbine from the competition rules.

Technical Challenges

Actuation Systems

A main part of the pitching mechanism is an actuation system, which must run as efficiently as possible. Two main options for this include hydraulics and electric motors. From researching the strengths of these different options it is clear that electric actuators are better suited for our application. For a hydraulic system to work, it would require double-acting cylinders as there are no external forces to retract the piston. A hydraulic system allows for easy synchronization between multiple actuators, however it operates at a lower efficiency, and has poor control mid stroke which is important to precise pitching. Furthermore with temperature variation, the oil (or other working fluid) will change density causing the system to require recalibration [11]. Electric motors (like stepper motors) operate more efficiently, have more precise control over position, which is crucial to pitching, however including several motors can be more difficult to synchronize [12]. While this narrows the design choice to an electrically powered linear actuator, more research is required to select the best model/style for our specific application.

Linkages

One of the potential design solutions involves a series of linkages to convert linear motion of an actuator into rotational motion to pitch the blades. Research into different four bar linkage types and their applications, as well as patents on linkage systems help provide insight into the best option for the pitching mechanism. There are two main joint types used in these linkages, a revolute joint, which provides rotation about an axis, and a prismatic joint, which is solely axial motion [13]. A linkage system of (RRRP) or a slider crank linkage allows linear actuation to be converted into rotational motion about a fixed point [14], which is the most applicable in our case. Further research is needed into the appropriate sizes and geometries of this design to provide the optimal pitch angle range while reducing the axial footprint of the design. From researching patents on linkages to convert linear into rotational motion, we found that including a pivot pin/lin can help to increase the range of motion as shown in the figure below [15]. However this design can only accommodate linear input for a portion of its range of motion, therefore further research would be required to determine if this would allow for a large enough pitching range, and if the benefits if provided justified the additional complication of the design.

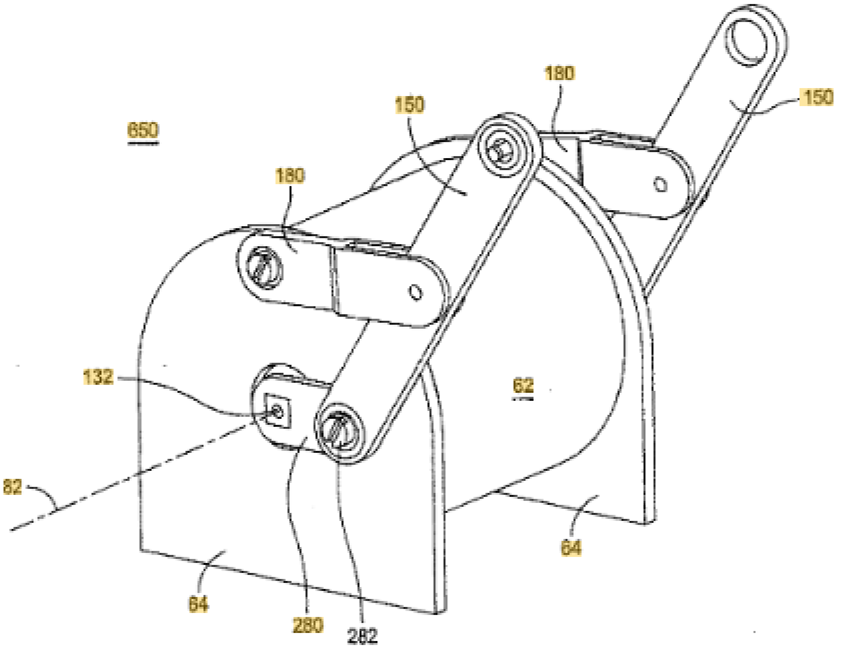

Figure 1: Pivoted four bar linkage solution

Gears

Gears are a common way to convert translational motion to rotational motion which is likely something that will be needed in this project. The previous senior project that built a pitching mechanism for the Cal Poly Wind Power club used a rack and pinion. While this mechanism does work as intended, the rack and pinion were made out of delrin which is a thermoplastic used in situations where high stiffness and low friction is needed. Over time the delrin has become worn down and the rack and pinion are no longer as rigid as they initially were on the pitching mechanism. This causes slippage between the gears and creates inaccuracy in the angle the blades are pitched to. As such, it was decided that any gears used on this year's design would be metal.

While this project has primarily been geared towards researching the translation of linear motion to rotational motion as a pitching mechanism, rotational motion to rotational motion is another avenue that may be taken. This would likely be done via the bevel gear. *Shigley's Mechanical Engineering Design* explains that "When gears are used to transmit motion between intersecting shafts, some form of bevel gear is required" [16]. They go on to further elaborate that "Although bevel gears are usually made for a shaft angle of 90°, they may be produced for almost any angle. The teeth may be cast, milled, or generated." Depending on the angle required for this project, the gears will either be milled or purchased off shelf but that has yet to be decided.

Lead Screws

Lead screws are what are known as power screws which are devices that change angular motion to linear motion and, in many cases, transmit power [16]. In the context of this project, they may be used to pitch the blades with a linear actuator attached to the lead nut and the blades attached to the lead screw in some fashion.

Anodizing

According to *The Metallurgy of Anodizing Aluminumby* Jude Mary Runge, "All industries that employ the high strength-to-weight ratio of aluminum and its alloys… look to the anodizing process as an important means to finish a variety of components manufactured in a variety of ways, with the robust and beautiful anodic oxide in order to provide corrosion protection, wear resistance and in many applications, decorative appearance" [18]. Wind turbines are often very exposed to the elements and, along with making an efficient pitching mechanism, making parts that last is another goal of this project. Anodizing is how this task is planned on being completed. One of the challenges this brings up is the thickness that is added to parts by anodizing them. Depending on the anodizing process and class thicknesses from 8 µm to as high as 125 µm in some cases can be achieved [18]. According to the *Anodic Coatings for Aluminum and Aluminum Alloy* revision F from the military, thicknesses can range from .00002 of an inch to .0045 of an inch depending on the process [19]. These values align with the values discussed in *The Metallurgy of Anodizing Aluminum*. Depending on the tolerances held over the course of this project, thickness of any anodize layer may or may not be critical. If the thickness is deemed critical to production, then the thickness will have to be accounted for in the design process or at least scaled once manufacturing occurs. The thickness achieved over the course of this project will likely need to be measured via a test anodize initially as getting an exact thickness will likely be something that proves challenging for first time anodizers. Ultimately, the goal of anodizing aluminum parts for this project is to give them better wear resistance. Hopefully a uniform repeatable thickness can be achieved.

Swashplates

The current pitching system is a rack and pinion system moved axially via a swashplate connected to two linear actuators, one on each side. The design was functional but has reached limitations in precision as previously discussed. The power draw for the linear actuators is from an outside source and the diameter is relatively large, which no longer fits the criteria of the design [19]. Given these critiques of the original design, there is opportunity for iteration. Norman Ham at the Massachusetts Institute of Technology advocates for the active control of swashplates for the control of helicopter blades, though the application is slightly different. Keeping the actuators stationary but influencing the rotating the components reduces the complexity and weight of the rotor [20]. Alternative styles of swashplates have been patented. One design suggests two swashplates, one rotating, one still, separated by a ball bearing [21]. Another design elaborates on a typical swashplate by incorporating gimbal rings for advanced control of swashplate position [22].

Helicopters

Similarly to wind turbines, helicopters must control the pitch of rotating blades from a non-rotating command center. Many helicopter blades and hubs are not large enough to house individual motors the way that commercial scale turbines do, so they are a promising model for a smaller scale turbine's blade pitching system. Helicopters traditionally employ a swashplate design, and there are several "active rotor control techniques currently available" including blade feathering, full blade twist, and jet flaps. One of the active rotor control approaches includes actuators located on a linkage between the swashplate and the blades for individual blade control [23]. While individual blade control is contradictory to our design constraints, the concept of using linkages was further researched.

Upon a more specific look at helicopters, there have been instances of development of swashplateless blade control. Locating the actuators in the rotor eliminates the need for a swashplate, however they must be as small and light as possible because they now contribute to the inertia of the rotor. Hydraulic, piezoelectric, and electromechanical actuators were evaluated for their capability [24]. So long as power can reach the rotor, small actuators may be able to limit the overall weight of the system by eliminating a swashplate. The desired diameter of the pitching system would require an actuator of potentially unattainably small sizes within the provided budget, however, further research into actuators was conducted.

Another swashplateless design was an articulated rotor hub with counterbalanced blades designed specifically for small, unmanned helicopters. This system was also a passive system, which is intriguing regarding the pitching system's low power requirement. The design does rely on a constant or near constant rotor speed which is achievable with an input motor in a helicopter, but less so with variable wind conditions in a turbine [25].

Unfortunately, many of these control techniques are designed to accommodate cyclic patterns that are present in helicopters and not in wind turbines. Whereas helicopter blades experience alternating wind patterns as blades move into the oncoming wind in the direction of travel or with the wind opposite the direction of travel. Because wind turbines are stationary, they do not experience this cyclic wind pattern, so many of the styles for helicopter blade pitching, which focus on pitching blades individually, are more complex or not suited for a wind energy application. However, the extensive development in this field provides a wide range of starting places for the design of the pitching system for a wind turbine.

Project Scope

The main goal of the project is to optimize blade angle into the wind in order to optimize energy capture. The criteria in measuring success of the project will come from the CPWP and the CWC rules.

At the core of our project our goal is to design, build and test our mechanical pitching mechanism. The actual controls of the pitching mechanism are outside of the scope of our project and will be handled by CPWP but we must provide a physical platform that will be ready to accept the turbines on board electronics. User-friendly design will be a big emphasis for our project as once we turn the project back over to the CPWP, it will be crucial that they will be able to take our product, use it, maintain it, and iterate on it. Below is the boundary diagram for the project, illustrating the exact parts of the projects our team will be responsible for.

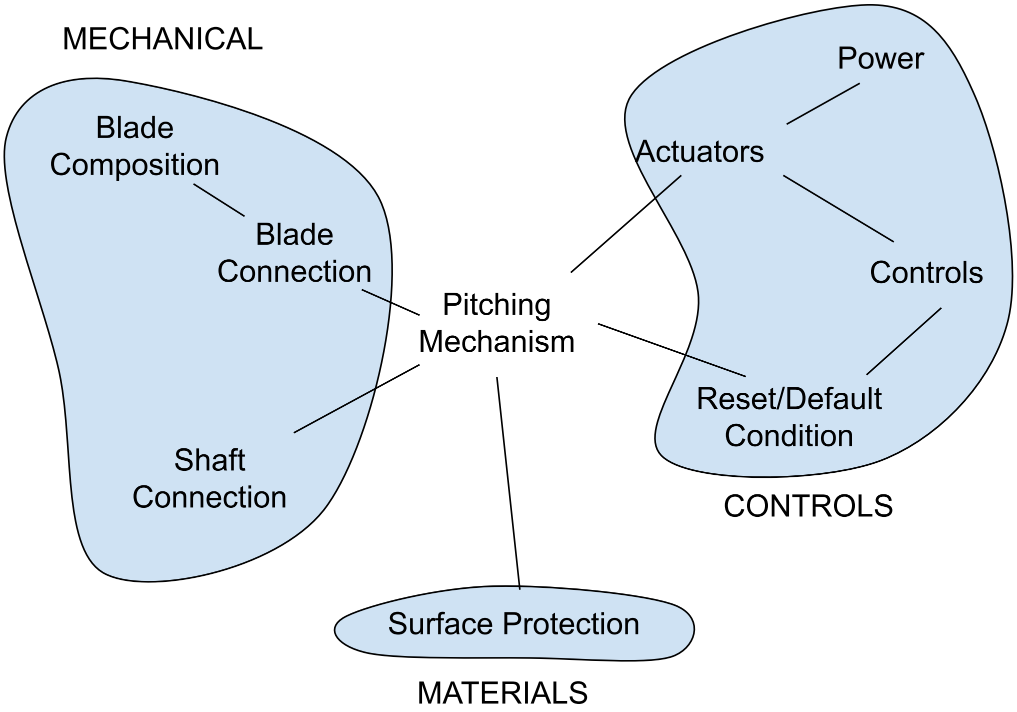

Figure XX: Boundary Diagram

Customer Needs and Wants

The CPWP has tasked us with this project and our main points of contact with in the club will be Trevor Ortega, the Drivetrain and Structures lead and Lily Goldman, the Power Lead, and Josephine Maiorano, who is a member of our project and also the Blades Lead. Each of these teams have different needs and wants from the pitching mechanism. We have been give a flexible budget of 3000 dollars with 2000 in reserve if we run into problems. A more detailed list of customer needs and wants can be found in the QFD (**Attachment 1**).

Drivetrain and Structures:

- Only takes up a small depth on the driveshaft
- Lightweight
- Does not interfere with shaft or bearings
- Durable design
- User friendly design

Power:

- Interfaces with turbine electronics
- Interfaces with turbine control system

Blades:

- Must be matable with blades
- Easy to interchange different blades
- Maintains pitch angle
- Returns to “zero” position for optimal wind cut in
- Maximize available blade area

The primary customer for the project is the CPWP but it will also be crucial to remember that they are competing in a competition with the CWC. As a result our design work must fall strictly within the CWC rules and regulations. Our team has read through this document to understand the most important rules as they pertain to the project. Additionally we will have to follow the competitions timeline and complete the relevant design milestone documents as they arise.

CWC:

- Follows 2022-2023 CWC Rules and Regulations
- Powered entirely by turbine
- Mates with CPWP turbine

Functional Decomposition

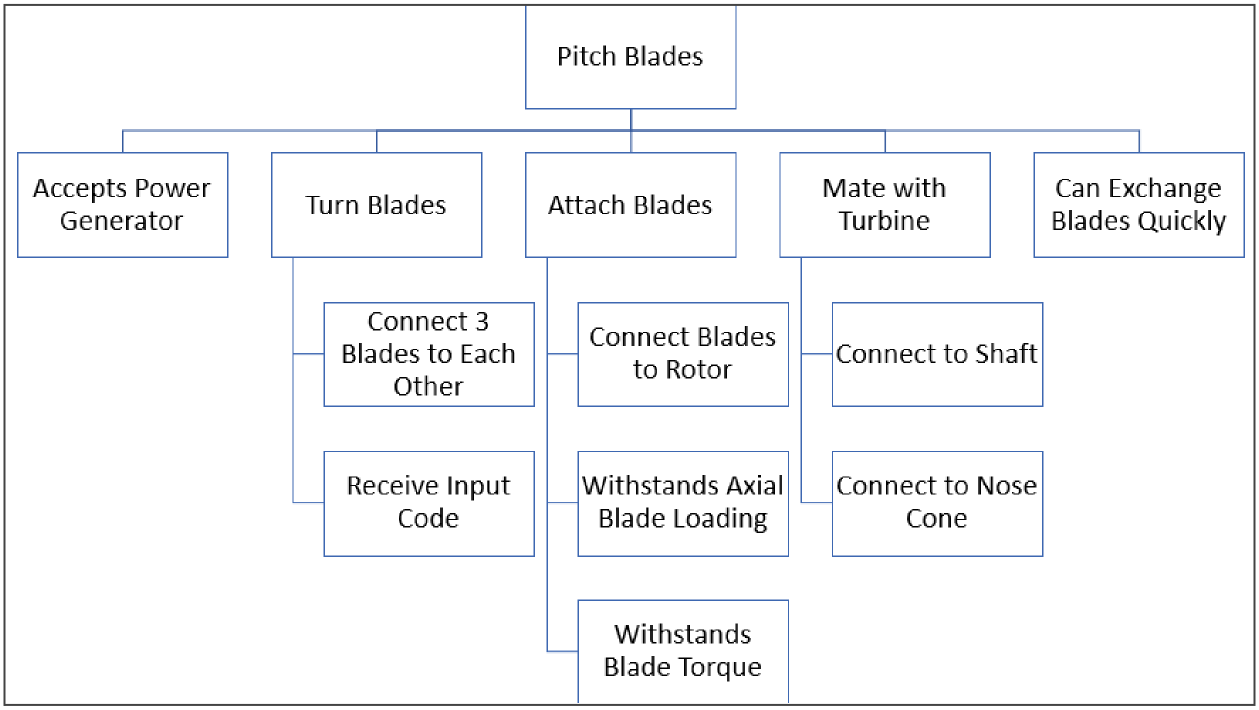

Figure X: Functional Decomposition

Objectives

Problem Statement

The goal of this Senior Design Project is to provide Cal Poly Wind Power with a blade pitching system for their small scaled competition wind turbine in order to optimize the power output of their turbine.

Quality Function Deployment

In order to accomplish this goal, a Quality Function Deployment House of Quality was created. The customers are defined as the Collegiate Wind Competition (hereafter referred to at "the CWC") which is the governing body for the design of Cal Poly Wind Power's turbine; the Cal Poly Wind Power blades team, who dictates the necessary functions of the system and whose products will directly interact with the pitching system and must mate properly; the Cal Poly Wind Power power team, who will provide the power and assist with the controls for the pitching system; and the Cal Poly Wind Power drivetrain and structures team, who designs the shaft onto which the system will be mounted as well as the housing for any additional components.

The customer requirements were defined through their project proposal as well as by interview and discussion in which they reflected on the previous design and described the goal of the new one. Fitting the CWC criteria and mating with the rest of Cal Poly Wind Power's turbine were weighed the largest of these requirements as the employment of the design is dependent on them. If these requirements are not met, the team's competition status is jeopardized. Similar objectives that received their own categories are interfacing with the turbine electronics and controls. A user friendly design with an easy blade interchange capability was also made a priority. The final dominating request was to maintain the specified pitch angle. Other requirements include durability, diametral size, weight, depth, and default conditions.

The current products in this field are the designs that previous CWC teams have implemented into their turbines. All previous design reports are published on the competitions website and the competition can be evaluated for efficiency, weight, precision, and other criteria of the design challenge. The pitching systems from four schools as well as the existing Cal Poly Wind Power design were established as the current products.

Engineering Specifications

These customer requirements were then broken down into twelve engineering specifications listed in **Table 1**, which were compared to the customer requirements and to each other. Their comparisons can be viewed in detail in **Attachment 1**.

Table 1: Engineering Specifications Table

Spec. #	Specification Description	Requirements or Target [units]	Tolerance	Risk	Compliance
1	Pitch Angle Range	45 [deg]	± 5	L	A,I,T
2	Base Circle Diameter	3 [cm]	max. + 0.5	L	A,I
3	Axial Depth	7 [cm]	max.	L	A,I
4	Weight	50 [g]	± 5	M	A,I
5	Axial Blade Load Strength	18 [N]	min.	H	A,T
6	Blade Torque Strength	5 [N]	min.	H	A,T
7	Power Storage	10 [J]	max.	H	A,S
8	Actuator Voltage	9 [V]	max.	H	A,T
9	Pitch Angle Accuracy	3 [deg]	max.	M	A,I
10	Blade Switch Time	15 [s]	± 5	M	T

11	Mate with Shaft	pass/fail	-	H	T
12	Mate with Nosecone	pass/fail	-	L	T

The specifications, in more detail, are as follows:

1. **Pitch Angle Range**: the axial mobility of each blade, which will likely be assessed by a combination of the blade root diameter and the distance that some actuator must travel
2. **Base Circle Diameter**: the diameter of the mechanism up until the first airfoil of the blades, which can be minimized by employing small components and simplicity
3. **Axial Depth**: the space along the shaft taken up by the pitching system outside of the nacelle as a cantilever on the shaft, which should be minimized, simplicity would help
4. **Weight**: the overall weight of the pitching mechanism, which should be minimized as weight overall is a graded element of the CWC, and can be accomplished by material selection and simplicity of design
5. **Axial Blade Load Strength**: the mechanism must be able to withstand the axial loading created in a sail-like manner from the wind on the blades, and should be factored in as a moment at the blade root when performing analysis
6. **Blade Torque Strength**: the strength associated with being able to rotate the blades when there is an opposing force due to the wind, which will be overcome structurally and by the strength of the actuator
7. **Power Storage**: the amount of reserved power not being used but available for use, which cannot exceed the limit set by the CWC and could be contained in a small stationary unit
8. **Actuator Voltage**: the amount volts that the actuator can draw upon to move the blades, which will be drawn from the generator, must be minimized because it reduces the measured power production of the turbine, which is a CWC graded element and will be carefully considered when choosing actuators
9. **Pitch Angle Accuracy**: the pitching mechanism must be able to rotate the blades to a specified angle to the previously noted degree of accuracy for optimal turbine performance, which can potentially be accomplished with small angle change for large actuator movement to maximize precision
10. **Blade Switch Time**: the length of time necessary for one of the members of Cal Poly Wind Power to be able to exchange the blades loaded in the pitching mechanism, which is critical for blade testing events as well as in the case of blade failure, which can be done using attachment methods with minimal removable pieces
11. **Mate with Shaft**: the pitching system must fit onto the shaft for this pass/fail specification, which will be assured through coordination with the Cal Poly Wind Power Drivetrain and Structure team

12. **Mate with Nosecone**: the pitching system should fit with the nosecone that resides on the front of the shaft, which will be assured through coordination with the Cal Poly Wind Power Blades team and Drivetrain and Structures team

There are five high risk specifications listed: Axial Blade Load Strength, Blade Torque Strength, Power Storage, Actuator Voltage, and Mate with Shaft. The two strength specifications are high risk because they are defined by the loading conditions present when the turbine is in the wind and become safety-critical elements should they fail. If the mechanism cannot maintain the strengths, either the mechanism or the blades may break and be flung due to a high rotational speed, which is a safety concern for anyone nearby. The power storage specification is defined by the CWC, and if the maximum power limit is exceeded, the turbine will not be eligible to compete in the competition. The actuator voltage specification is based on availability of power based on predicted generator output. If the actuators require more power, they may not have access to it. Finally, it is not optional for the mechanism to mate with the shaft, because if the mechanism cannot mate with the shaft, it cannot be used.

Project Management

In order to complete this design project, there will be rigorous adherence to the timeline to ensure prompt and quality work is completed. Fall quarter will be spent performing a literature review, which is mostly complete, ideation and narrowing of design options, and the development of the final design. This will include creating a detailed CAD model of our design that is ready for manufacturing as well as all appropriate strength and performance calculations, including FEA analysis and pitch range calculations. Winter quarter will be spent manufacturing in the first few weeks, and then testing to ensure the pitching mechanism is ready for full turbine testing several weeks before the CWC subassembly assembly and testing milestone in the beginning of april. Spring quarter shall be spent writing reports and creating documentation for our projects, which includes writing the pitching portion of the CWC turbine design report. The key milestones can be seen below in **Table 2**, as well as additional details, especially for the first quarter, available in our Gantt chart (**Attachment 2**).

Table 2: Key Milestones

Milestone	**Respective Client**	**Date**
Scope of Work	Senior Design	10/19/2022
Conceptual Design Report	CWC	10/27/2022
Design Review	CPWP	11/16/2022
Preliminary Design Review	Senior Design	11/17/2022

Preliminary Turbine Design Report	CWC	12/08/2022
Interim Design Review	Senior Design	01/24/2023
Critical Design Review	Senior Design	02/16/2023
Subassembly Assembly and Testing Milestone	CWC	04/13/2023
Turbine Design Report	CWC	05/04/2023
Collegiate Wind Competition	CWC	05/21/2023-05/24/2023
Final Design Review	Senior Design	06/09/2023

Some of the resources available to achieve quality results with this project include various CAE softwares including Matlab, Simulink, Fusion360 and the corresponding FEA software. Additionally access to extensive machine shops for prototyping and manufacturing, including a 5-axis CNC machine, allow for manufacturing complex parts from durable materials. Also an ample funding budget generously provided by CPWP will ensure quality materials and parts are used. For testing access to sophisticated testing equipment, including fish scales, optical sensors, and a rotational safety test box, and a wind tunnel will be integral to verify the validity of our design.

Leading up to the next major milestone, the preliminary design review as well as the CPWP design review in mid November, a complete design of the pitching mechanism will be prepared. Achieving this includes narrowing the current design idea by choosing an actuation style, blade connection style, and linkage style. The preliminary design outline will be created providing dimensions and values to begin analysis, and iteration. An initial prototype will be created at this phase to show proof of concept. Strength and power requirements will then be determined to select actuators. The shape and strength of the stationary to rotational push plate will also be determined. The range of motion and space requirements for the linkage arms will be calculated as well as FEA performed based on loading conditions supplied by the CPWP and updated as more accurate numbers become available. The general hub shape to accommodate the blades and pitching mechanism will be determined as well as the loads it will carry and selecting bearings for the blades. The cross sectional shape of the blade root will be chosen, as well as a securing mechanism into the hub. After iterating to ensure our design meets the specifications, final CAD design in fusion 360 will be created for the whole assembly indlucign the actuator system, push plate, linkage arm, hub and blade root. There will also be regular communication with the CPWP to ensure the latest geometries and loads are being used for calculations by both the TIPS team and the CPWP team. This design will be finished before the CPWP design review, and a more indepth PRD report will be provided shortly thereafter. A brief description of the design will also be provided as appropriate for the CWC preliminary turbine design report.

Conclusion

The aim of the TIPSY senior project is to design and manufacture a lightweight, compact, precise, and accurate blade pitching mechanism for CPWP's wind turbine that will be competing in the CWC in June of 2023. The goal of this document is to define the problem this project will be solving, highlight the research that has been completed on the scope of the project, talk about the customer's needs and wants, outline the initial design constraints and criteria, and create a timeline for the completion of this project. The primary purpose of this mechanism is to allow the wind turbine to optimize energy capture depending on the speed of the wind. The previous iteration allowed the blades to pitch but since the rack and pinion mechanism that did the pitching was made from delrin, it has worn down and no longer provides control to the accuracy and precision that CPWP desires. In order to ensure that the pitching mechanism designed over the course of this project remains accurate and precise in the long run, most, if not all parts will be made of aluminum or some sort of lightweight metal. For the exact design parameters of this project, the CWC posts yearly competition documentation that will be followed. Additionally, as this project is being sponsored by CPWP, there will be a large amount of collaboration between the subtrams of the club and the members of this project especially with interfacing. The electrical work and control system will be handled by the appropriate subteams on CPWP while this team will be designing and manufacturing the entirety of the mechanical parts to the project. In order to ensure that there is avid communication occurring between this project and CPWP, we are submitting this document for their approval and will also be completing and submitting a preliminary design for review by 11/17/2022.

References

[1]

“Collegiate wind competition rules and requirements,” *Energy.gov*, 31-Aug-2022. [Online]. Available: https://www.energy.gov/eere/collegiatewindcompetition/articles/collegiate-wind-competition-rules-and-requirements. [Accessed: 14-Oct-2022].

[2]

kansas 2022

[3]

northern arizona 2022

[4]

james madison 2022

[5]

johns hopkins 2021

[6]

penn state 2021

[7]

Schottler, Jannik & Hölling, Agnieszka & Peinke, Joachim & Hölling, Michael. (2016). Design and implementation of a controllable model wind turbine for experimental studies. Journal of Physics: Conference Series. 753. 072030. 10.1088/1742-6596/753/7/072030.

[8]

Abdel Gawad, Ahmed. (2013). New, Simple Blade-Pitch Control Mechanism for Small-Size, Horizontal-Axis Wind Turbines. Journal of Energy and Power Engineering. 7. 2237-2248. 10.17265/1934-8975/2013.12.004.

[9]

https://www.youtube.com/watch?v=pHFHv0sckvw

[10]

Pitch Control Critical for Wind Power | Machine Design

[11]

https://www.tolomatic.com/info-center/resource-details/electric-rod-actuators-vs-hydraulic-cylinders/

[12]

https://www.tolomatic.com/blog/motor-selection-for-electric-linear-motion-stepper-vs-servo/

[13]

https://web.archive.org/web/20090311072110/http:/www.robotics.utexas.edu/rrg/learn_more/low_ed/joints/

[14]

https://en.wikipedia.org/wiki/Four-bar_linkage

[15]

https://patents.google.com/patent/JP6551948B2/en?q=%27four+bar+linkage%27&oq=%27four+bar+linkage%27&page=1

[16]

Shigleys

[17]

The Metallurgy of Anodizing Aluminumby Jude Mary Runge

[18]

Anodic Coatings for Aluminum and Aluminum Alloy

[19]

Hartley, Jenna, et al. San Luis Obispo, California, 2020, pp. 7–53, Cal Poly Wind Power - Blade Pitching System Critical Design Review Report.

[20]

Ham, Norman D. National Aeronautics and Space Administration, Moffett Field, California, 1993, pp. 1–12, Improvement of Helicopter Attitude Stability by Active Control of the Conventional Swash Plate.

[21]

Habibvand, Alex. Swashplate Assembly. 29 Jan. 2009.

[22]

Peyran, Richard J., et al. Swashplate Control System. 2 June 1987.

[23]

Reduction of Helicopter Blade-Vortex Interaction Noise By Active Rotor Control Technology

[24]

Development of swashplateless helicopter blade pitch control system using the limited angle direct-drive motor (LADDM)

[25]

Cyclic Blade Pitch Control Without a Swashplate for Small Helicopters

Appendix

Attachment 1	QFD
Attachment 2	Gantt Chart