Strength analysis for designing a bicycle transmission system without chain

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Abstract. Bicycles have several advantages over other transportation, one of which is its environmentally-friendly characteristic. The strength analysis consists of a series of strength calculations and simulations to save time and cost in the component design of a bicycle transmission system without chains. The design of a bicycle transmission system without a chain uses the French method, which begins by analyzing the needs based on a transmission system that already exists in the field and ends with a working picture of the strength analysis of a modified bicycle that has a chainless transmission system. The design of a bicycle transmission system without a chain is divided into two types of designs using the principle of the four connecting rod mechanism. Analysis of the power design shows that the two types of design of a bicycle transmission system without a chain work well as a bicycle transmission system. Keywords: strength analysis, french method, bicycle transmission, four bar linkage mechanism.

1. Introduction
The development of transportation in Indonesia is growing rapidly, one of which is developing a bicycle. Bicycles being an option in product development because they have several advantages over other transportation, which are environmentally friendly. In general, bicycles use a chain and sprocket transmission system to transfer power generated by the rider to the pedals of the pedaled bicycle [1-2]. The bicycle pedal connected to the sprocket then transfers power through the chain to the rear wheels which also have a sprocket so the bike can move. The weakness of the chain and sprocket transmission system on bicycles that often occurs is broken chain or chains that loose. In addition, the chain and sprocket transmission system need maintenance so that the power transfer remains optimal. Required maintenance such as chain lubrication, checking chain tension, and cleaning the chain and sprocket from dirt. Chain and sprocket transmission systems can cause harm to the rider, the rider can be injured due to being hit by the chain and sprocket when using a bicycle. Weaknesses and losses inherent in chain and sprocket transmission systems can be overcome with a chainless transmission system. This design is expected to increase the use of bicycles as a personal transportation, so as to reduce air pollution which is increasing every year. In this design, a bicycle with a chain and sprocket transmission system is used to be replaced with a chainless transmission system with the same bicycle frame [3-5]

2. Method
The method used in the analysis of the power design of a bicycle transmission system without chains is the French method. Design with the French method begins by clarifying the needs of
the bicycle transmission system that requires little maintenance. Clarification of the needs of bicycle transmission systems results in two types of bicycle transmission systems without chains using the principle of the four connecting rod mechanism [6-7]. Strength analysis will focus on two chainless bicycle transmission systems designed because the frame of the folding bike used is considered strong.

The strength analysis carried out includes components contained in the bicycle transmission system without chains, such as connecting rods, connecting pins, flywheels, shafts on the flywheel, pins for pedals, and shafts on the pedal rods. Strength analysis using calculations [5-8] which has the assumption that the bicycle has a maximum speed of 20 km/h and simulation on Autodesk Fusion 360 software. The results of the strength analysis on both designs will be used for conclusion to determine a design that can work well.

The flow chart used in the analysis of the power design of a bicycle transmission system without this chain is as follows:

![Flowchart](image)

**Figure 1. Flowchart of strength analysis for designing a Bicycle without chains**

### 3. Result and Discussion

Analysis of the strength of a bicycle transmission system without a chain begins with the selection of bicycles to be modified. In this research, exotic 2.0 brand folding bikes were chosen. The next step is re-drawing using the dimensions of a folding bike that will be modified without a transmission system using the Autodesk Fusion 360 software. CAD depiction consists of several major components on a folding bicycle such as bicycle frame parts, front set parts,
and saddle areas [1-2]. The folding CAD bicycle that has been drawn form the basis for making the dimension of the bicycle transmission system design without chains. The design of a bicycle transmission system without chains is made of two types using the four connecting rod principle. In this design, we have obtained two designs which then carried out strength test simulations using software. After designing CAD using Autodesk Fusion 360 software, a finite element analysis (FEA) was performed with the same software regarding safety factors, von misses stress, strain, and deflection that occurs in a bicycle transmission system component without the first design chain and the second design. The simulation is based on the assumption of a maximum pedal tread force of 400 N on the left bicycle pedal pin and the right bicycle pedal pin, a rider weight of 80 kg, and a bicycle load of 20 kg [8-13]. The following are the results of simulations and mathematical calculations that regarding safety factors, stresses, strain, and displacement in the design of bicycle transmission systems without chain first and second design:

Table 1. Stress that occurs in component of first design and second design

| Stress (MPa)                      | First Design       | Second Design      |
|----------------------------------|--------------------|--------------------|
|                                  | Mathematical Calculation | FEA     | Mathematical Calculation | FEA     |
| Shear stress at rear shaft       | 49.34              | 71.11              | 59.64              | 113.6   |
| Bending stress at rear shaft     | 62.83 / 124        | 106.69 / 107.33    | 79.84              |
| Bending stress at pedal link’s shaft | 90.52              | 56.6               | 102.35             |
| Bending shaft at link pedal      | 66.704             | 65.64              | 51.94              | 48.24   |
| Shear stress at link pedal       | 33.504             | 26                 | 93.44              | 64.97 / 71.69 | 59.11 |
| Bending stress pedal pin at pedal link | 36.47              | 14.6               | 15.38              | 4.24    |
| Bending stress pedal link’s shaft at pedal link | 32.18              | 65.64              | 4.24               |
| Bending stress coupler pin at pedal link | 29.11              | 14.1               |                     |
| Bending stress pedal link at coupler pin | 29.11              | 59.11              | 16.92              | 76.83   |
| Bending stress coupler link at flywheel | 29.11              | 16.92              |                     |
| Bending stress flywheel at coupler link | 34.93              | 50.76              | 62.71              |
| Bending stress flywheel at rear shaft | 31.3 / 63.37        | 32.17              | 32.1 / 32.3        |
| Bending stress at pedal pin      | 144.828            | 136.8              | 96.552             | 98.98   |
Table 2. Strain that occurs in component of first design and second design

| Strain (E-4)           | First Design                  | Second Design                  |
|-----------------------|-------------------------------|--------------------------------|
|                       | Mathematical Calculation | FEA | Mathematical Calculation | FEA |
| Rear shaft            | 3.07 / 6.05                  | 1.357 | 5.2 / 5.24              | 2.699 |
| Shaft at pedal link   | 4.42                         | 2.699 | 4.99                     | 1.459 |
| Pedal pin             | 7.065                        | 7.437 | 4.71                     | 5.023 |
| Coupler pin at flywheel | 3.02                      | 1.414 | 3.17                     | 0.711 |
| Coupler pin at pedal link | 3.96                   | 1.255 | 3.5                      | 2.52  |
| Pedal pin at pedal link | 5.29                      | 1.414 | 3.17                     | 2.52  |
| Pedal pin at pedal link | 4.67                      | 1.414 | 3.17                     | 2.52  |
| Pedal link at coupler link | 4.22                 | 1.255 | 3.5                      | 2.52  |
| Coupler link          | 4.22                         | 1.499 | 2.46                     | 4.045 |
| Flywheel at coupler link | 1.7                      | 1.062 | 2.48                     | 1.208 |
| Flywheel at rear shaft | 1.53 / 3.09                | 1.062 | 1.57 / 1.58             | 1.208 |

Figure 3. Result of finite element analysis regarding safety factor of first design

Figure 4. Result of finite element analysis regarding safety factor of second design

4. Conclusion
The bicycle transmission system without the first design chain and the second design can function properly and has a safe construction if given a load on each pedal pin of 400 N based on mathematical calculations and analysis of the Autodesk Fusion 360 software. In the analysis of the first design software, the smallest safety factor is in the section pedal pin with a value of 3.771. Whereas in the second design software analysis, the smallest safety factor is located on the rear axle with a value of 4.544. Analysis of the strength of the design of a bicycle transmission system without chains is done with mathematical calculations and analysis of the Autodesk Fusion 360 software. The greatest stress obtained from the first design mathematical calculation is on the pedal pin section which is worth 144.8 MPa and from the second design mathematical calculation is on the rear axle which is worth 107.3 MPa. While the greatest stress obtained from the analysis of the first design software is on the pedal pin which is worth 136.8 MPa and from the analysis of the second design software is on the rear axle which is 113.6 MPa.
5. References

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