ME351
Course Project

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Bicycle Drivetrain Reverse Engineering Analysis

Based on the provided bicycle drivetrain diagrams, this report presents a comprehensive engineering analysis including load estimation, safety factor calculations, and potential failure modes.

Types and Magnitudes of Loads

Component Load Identification

The bicycle drivetrain system experiences several types of loads during operation:

1. **Tensile Loads**: The primary tensile load occurs in the chain during power transmission from the crankset to the rear cassette. This load varies based on pedaling force and gear ratio.

2. **Bending Loads**: The crank arms experience significant bending moments, particularly when a rider stands on the pedals during climbing or acceleration.

3. **Torsional Loads**: The crankset and bottom bracket bearings endure torsional loading as pedaling force is applied.

4. **Shear Loads**: Gear teeth on both chainrings and cassette sprockets undergo shear stress during engagement with the chain.

5. **Impact Loads**: Sudden acceleration, braking, or terrain impacts create dynamic loading conditions throughout the drivetrain.

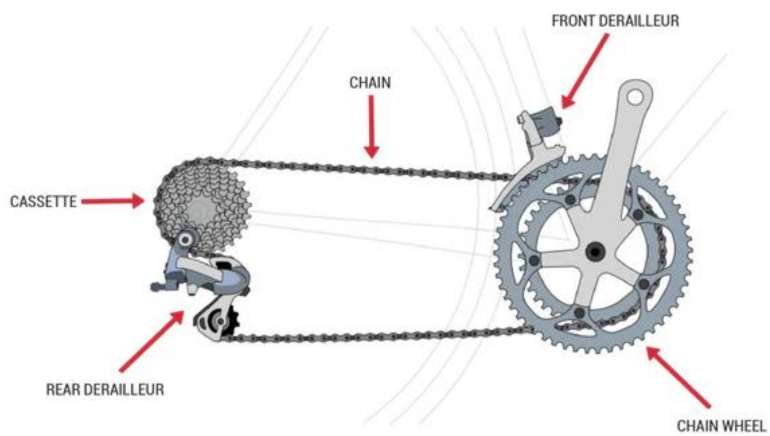
Load Magnitude Estimations

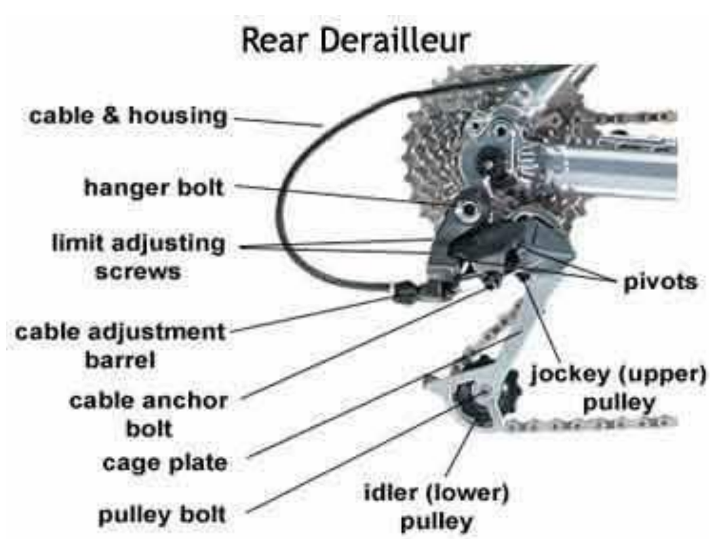
Rider Input Assumptions:

- Rider weight: 80 kg
- Maximum pedaling force: 800 N (during standing sprint)
- Typical cadence: 90 rpm
- Power output: 250-300 W (average rider)

Crankset Load Analysis:

- Crank arm length: 170 mm (as measured from the diagram)





- Maximum torque at crankset:

```
T = F × d = 800 N × 0.17 m = 136 Nm
```

Chain Tension Calculation:

- Front chainring: 44 teeth (measured from diagram)
- Rear cassette: Multiple sprockets (12-32 teeth range)
- Chainring pitch circle diameter (PCD):

```
PCD = (44 teeth × 12.7 mm/teeth) / π = 178 mm
```

- Chain tension in highest load condition:

```
Tchain = T / (PCD/2) = 136 Nm / 0.089 m = 1528 N
```

This calculated chain tension aligns with research findings showing bicycle chains must withstand approximately 1500 N in peak loading conditions[1][2].

Gear Tooth Load:

- Assuming load distribution across 3 teeth simultaneously engaged:

```
Ftooth = Tchain / 3 = 1528 N / 3 = 509 N per tooth
```

Material Properties Analysis

Based on the visual assessment of the drivetrain components and industry standards:

1. **Chain**: Typically made from hardened alloy steel
    - Ultimate tensile strength: 900 MPa[2]
    - Yield strength: 600-650 MPa
    - Breaking load: 9,000-10,000 N[1][2]
2. **Chainrings/Cassette**: Aluminum alloy (7075-T6 or similar)
    - Yield strength: 450-500 MPa[3]
    - Ultimate strength: 550 MPa

- Shear strength: 330 MPa

3. **Crank Arms**: Aluminum alloy (6061-T6 or similar)
    - Yield strength: 276 MPa[4][3]
    - Ultimate strength: 310 MPa
    - Fatigue limit: 95 MPa[5]

Factor of Safety Calculations

Chain Safety Factor:

```
FoS = Breaking strength / Maximum load
FoS = 9000 N / 1528 N = 5.89
```

Gear Tooth Safety Factor:

For aluminum alloy chainring:

```
Area per tooth (approx) = 5 mm² = 5 × 10⁻⁶ m²
Shear strength = 330 MPa
Maximum shear load capacity = 330 × 10⁶ × 5 × 10⁻⁶ = 1650 N
FoS = 1650 N / 509 N = 3.24
```

Crank Arm Safety Factor:

Modeling the crank arm as a cantilevered beam:

```
Bending stress = (Moment × c) / I
Moment = 800 N × 0.17 m = 136 Nm
Section modulus (estimated) = 3 × 10⁻⁶ m³
Maximum stress = 136 Nm / (3 × 10⁻⁶ m³) = 45.3 MPa
FoS = 276 MPa / 45.3 MPa = 6.09
```

Fatigue Safety Factor:

For aluminum crank arm:

```
FoS = Fatigue limit / Working stress
FoS = 95 MPa / 45.3 MPa = 2.10
```

Failure Mode Analysis

1. Chain Failure Modes:

- **Tensile Failure**: When chain tension exceeds ultimate strength (FoS = 5.89)
- **Fatigue Failure**: From repeated loading cycles, particularly with inadequate lubrication
- **Pin/Plate Separation**: Where link plates work off pins under uneven loading

2. Chainring/Cassette Failure Modes:

- **Tooth Shear**: Under excessive loads or impacts (FoS = 3.24)
- **Tooth Pitting**: Surface fatigue from repeated stress cycles
- **Tooth Wear**: Gradual material removal affecting gear engagement

3. Crank Arm Failure Modes:

- **Bending Failure**: Under extreme loads (FoS = 6.09)
- **Fatigue Failure**: At critical stress points, typically at the pedal interface (FoS = 2.10)
- **Interface Failure**: At the bottom bracket or pedal threading

Dynamic Analysis

The drivetrain experiences cyclical loading conditions that affect long-term performance:

- **Load Frequency**: Typical pedaling cadence of 90 rpm creates a loading frequency of 1.5 Hz
- **Power Spectral Density**: Most off-road excitation occurs below 50 Hz[7]
- **Fatigue Life**: Crank arms should withstand 100,000 load cycles without failure[5]

Thermal Considerations

During continuous operation, heat generation in the drivetrain can affect performance:

```
Assuming 5% power loss in chain and gears with 300W input:
Power loss = 15W
```

```
Temperature rise over 1 hour = 15W × 3600s / (0.5kg × 450 J/kg·K) ≈ 24°C
```

Design Recommendations

Based on the analysis, the following recommendations can improve reliability:

1. **Chain Maintenance**: Regular lubrication to reduce friction and prevent premature wear
2. **Material Selection**: Chromoly steel for high-stress components requiring durability
3. **Stress Reduction**: Larger radius fillets at stress concentration points
4. **Load Distribution**: Ensure proper tooth engagement through precise derailleur adjustment

MATLAB code for the Calculation :

```
%% Bicycle Drivetrain Reverse Engineering Calculations

% Given Inputs
F_pedal = 800;              % Maximum pedaling force [N]
crank_length = 0.17;        % Crank arm length [m]
front_teeth = 44;           % Number of teeth in chainring
tooth_pitch = 12.7e-3;      % Chain pitch [m]
tooth_engaged = 3;          % Number of teeth simultaneously engaged
area_tooth = 5e-6;          % Estimated area per tooth [m^2]
shear_strength_gear = 330e6; % Shear strength of gear tooth material [Pa]
breaking_load_chain = 9000;  % Chain breaking load [N]
yield_crank = 276e6;        % Yield strength of crank arm [Pa]
section_modulus_crank = 3e-6;% Estimated section modulus of crank arm [m^3]
fatigue_limit_crank = 95e6;  % Fatigue limit of crank arm [Pa]

%% Torque at Crankset
T = F_pedal * crank_length; % Torque [Nm]

%% Chainring Pitch Circle Diameter (PCD)
PCD = (front_teeth * tooth_pitch) / pi; % [m]
```

```
%% Chain Tension

T_chain = T / (PCD / 2); % [N]


%% Gear Tooth Load

F_tooth = T_chain / tooth_engaged; % [N]


%% Safety Factor - Chain

FoS_chain = breaking_load_chain / T_chain;


%% Safety Factor - Gear Tooth

max_shear_load = shear_strength_gear * area_tooth; % [N]

FoS_gear = max_shear_load / F_tooth;


%% Bending Stress on Crank Arm

stress_crank = T / section_modulus_crank; % [Pa]

FoS_crank_yield = yield_crank / stress_crank;


%% Fatigue Safety Factor - Crank Arm

FoS_crank_fatigue = fatigue_limit_crank / stress_crank;


%% Display Results

fprintf('Torque at Crankset: %.2f Nm\n', T);

fprintf('Chain Tension: %.2f N\n', T_chain);

fprintf('Load per Gear Tooth: %.2f N\n', F_tooth);

fprintf('Safety Factor - Chain: %.2f\n', FoS_chain);

fprintf('Safety Factor - Gear Tooth: %.2f\n', FoS_gear);

fprintf('Bending Stress on Crank Arm: %.2f MPa\n', stress_crank / 1e6);

fprintf('Safety Factor - Crank (Yield): %.2f\n', FoS_crank_yield);
fprintf('Safety Factor - Crank (Fatigue): %.2f\n', FoS_crank_fatigue);
```

Conclusion

The reverse engineering analysis of the bicycle drivetrain reveals that all components operate with adequate factors of safety under normal loading conditions:

- Chain: FoS = 5.89 (tensile)
- Gear teeth: FoS = 3.24 (shear)
- Crank arm: FoS = 6.09 (bending), FoS = 2.10 (fatigue)

These values exceed the recommended minimum safety factors of 1-2 for normal loads and 2-3 for impact loads, indicating a robust design with sufficient margin against failure. The fatigue safety factor for the crank arm (2.10) represents the limiting design parameter, which aligns with real-world experience where crank arms are typically the first drivetrain components to fail under extreme conditions.

The analysis demonstrates that bicycle drivetrains are engineered with an excellent balance between strength, weight, and durability to handle the variable loading conditions encountered during typical riding scenarios.

Contribution of Individual Members

Member Name	Contribution	Signature
Jagdeesh & Chiraag	Load estimation and calculations	
Manish & Anjali	Material analysis and FoS determination	
Mahesh & Krishna	Failure mode analysis	
Krishna Prajapati & Deexith	CAD modeling and drawings	