Vibration Signal Analysis

Early Detection of Mechanical Wear in Rotating Machinery

Complete Analysis Report

PHYS6017 - Computer Techniques for Physics

Assignment Two

Generated: December 30, 2025

Report Contents:

1. Parameter Settings and Configuration Tables
2. Time Domain Signal Analysis
3. Frequency Domain Analysis (FFT)
4. Digital Filtering Demonstration
5. Quantitative Wear Progression Indicators
6. Detailed Frequency Comparison
7. Parameter Sensitivity Analysis
8. Computational Methods Summary
9. Performance Metrics and Validation

Key Findings:

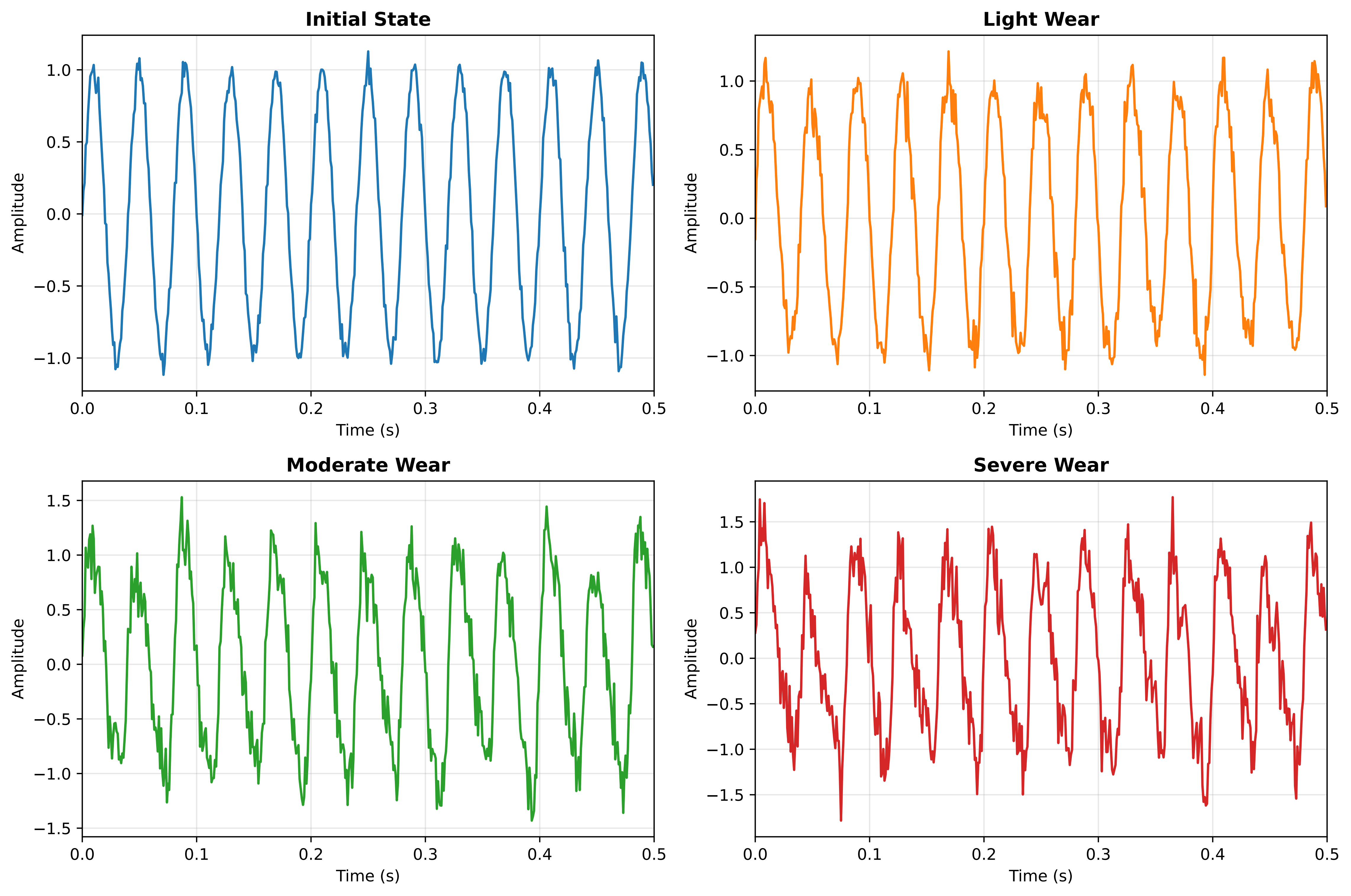
- RMS amplitude increases systematically with wear progression
- Harmonic content shows dramatic growth (>10x increase)
- High-frequency content indicates surface degradation
- Frequency-domain analysis enables early fault detection

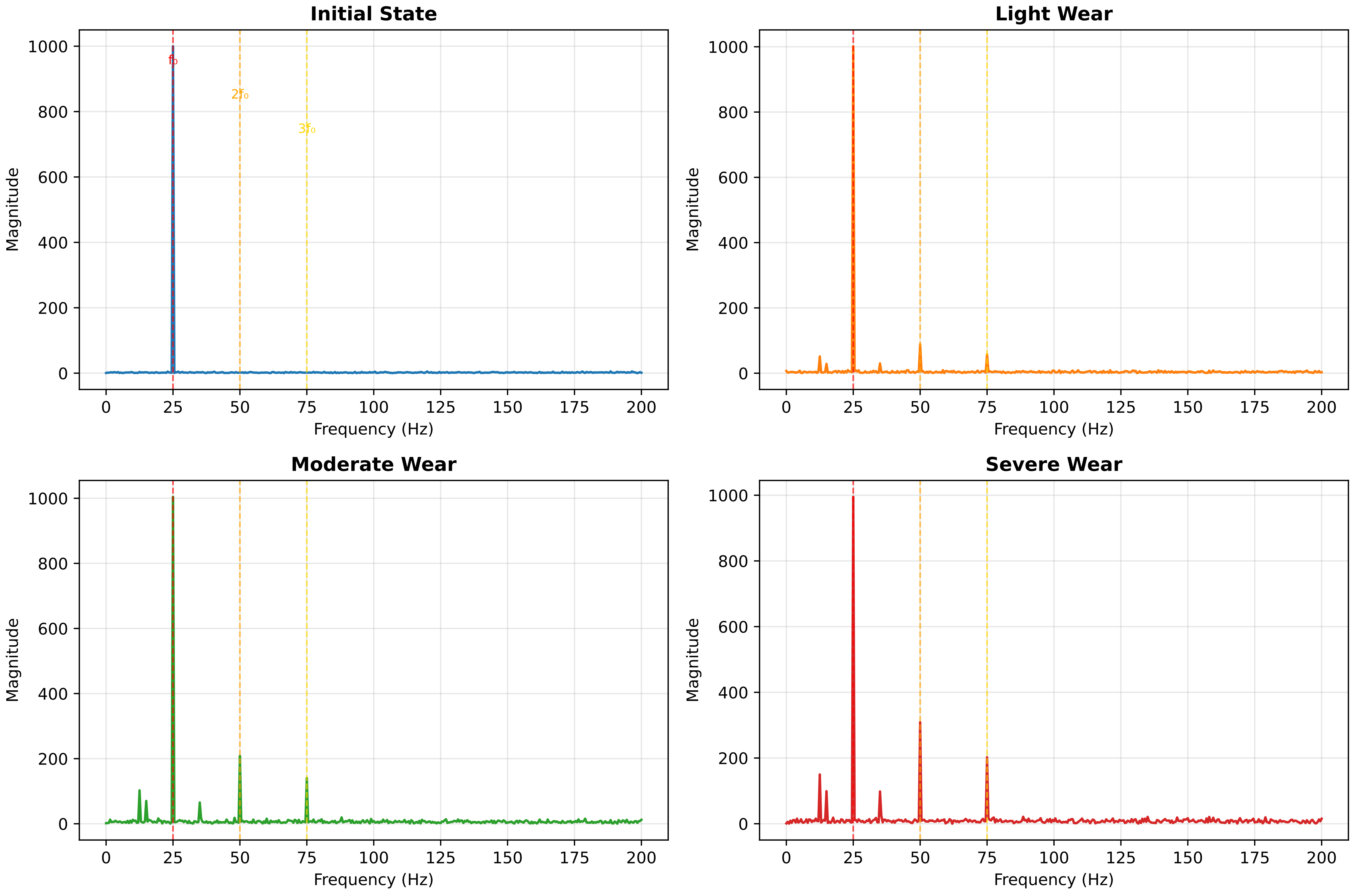
Parameter Settings and Configuration

Parameter	Symbol	Value	Units	Description
Sampling Frequency	fs	1000	Hz	Digital sampling rate
Signal Duration	T	2.0	s	Length of each signal
Number of Samples	N	2000	-	fs × T
Rotation Frequency	f_0	25.0	Hz	Fundamental frequency (1
Fundamental Amplitude	A_0	1.0	-	Base vibration amplitude
Noise Amplitude	σ	0.05-0.25	-	Gaussian noise std deviati
Wear Levels Tested	-	0.0, 0.3, 0.7, 1.0	-	Dimensionless wear sever
Filter Order	-	4	-	Butterworth filter order
Low-pass Cutoff	fc_low	50	Hz	Low-pass filter frequency
High-pass Cutoff	fc_high	50	Hz	High-pass filter frequency
Band-pass Range	fc_band	40-80	Hz	Band-pass filter range

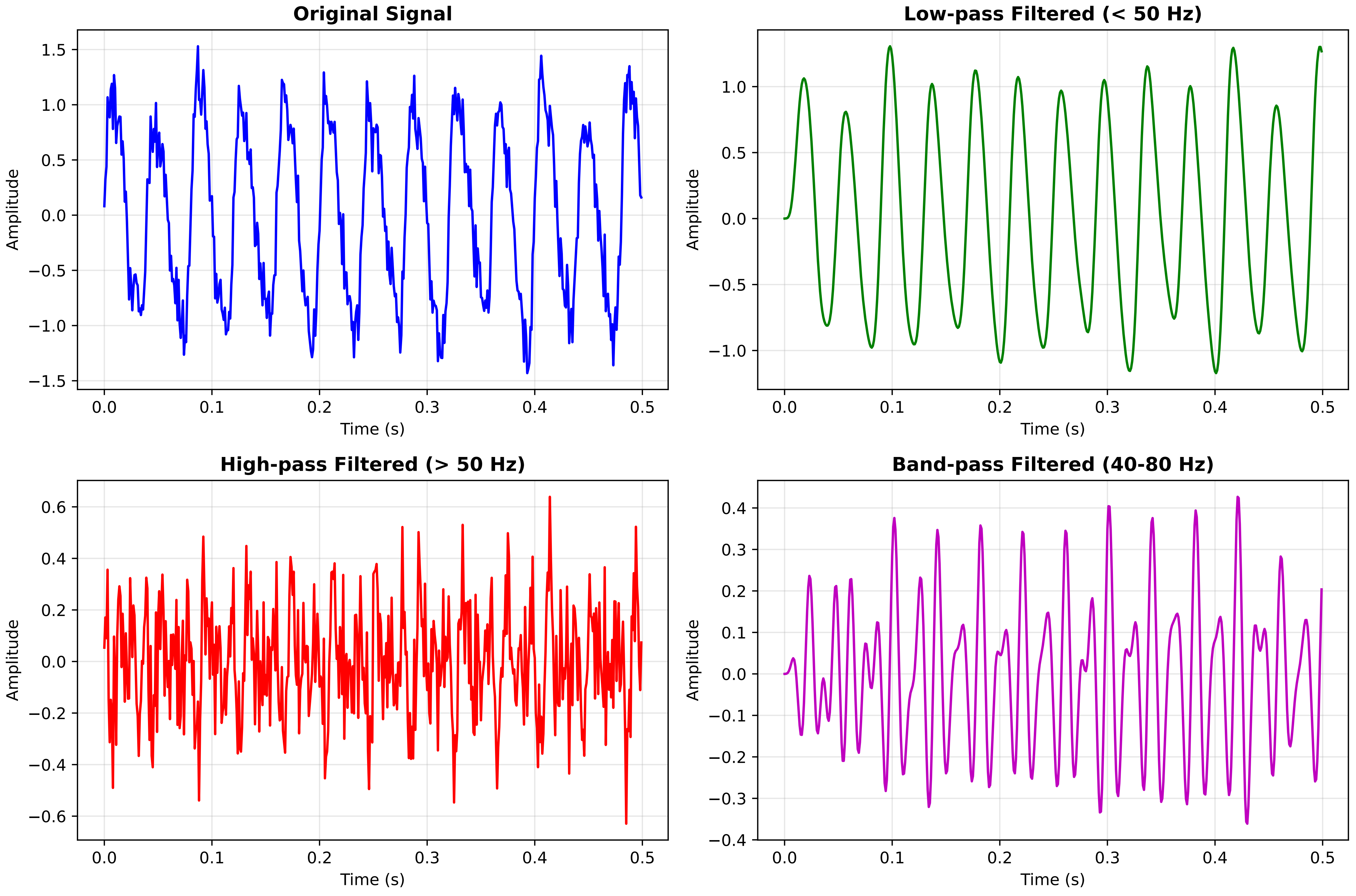
Wear-Related Frequency Components

Wear Component	Frequency	Amplitude Scaling	Physical Meaning
2nd Harmonic	$2f_0$ (50 Hz)	0.3 × wear_level	Nonlinear bearing response
3rd Harmonic	$3f_0$ (75 Hz)	0.2 × wear_level	Higher-order nonlinearity
Sub-harmonic	$0.5f_0$ (12.5 Hz)	0.15 × wear_level	Intermittent contact
Upper Sideband	f_0 + 10 Hz (35 Hz)	0.1 × wear_level	Modulation effects
Lower Sideband	f_0 - 10 Hz (15 Hz)	0.1 × wear_level	Modulation effects

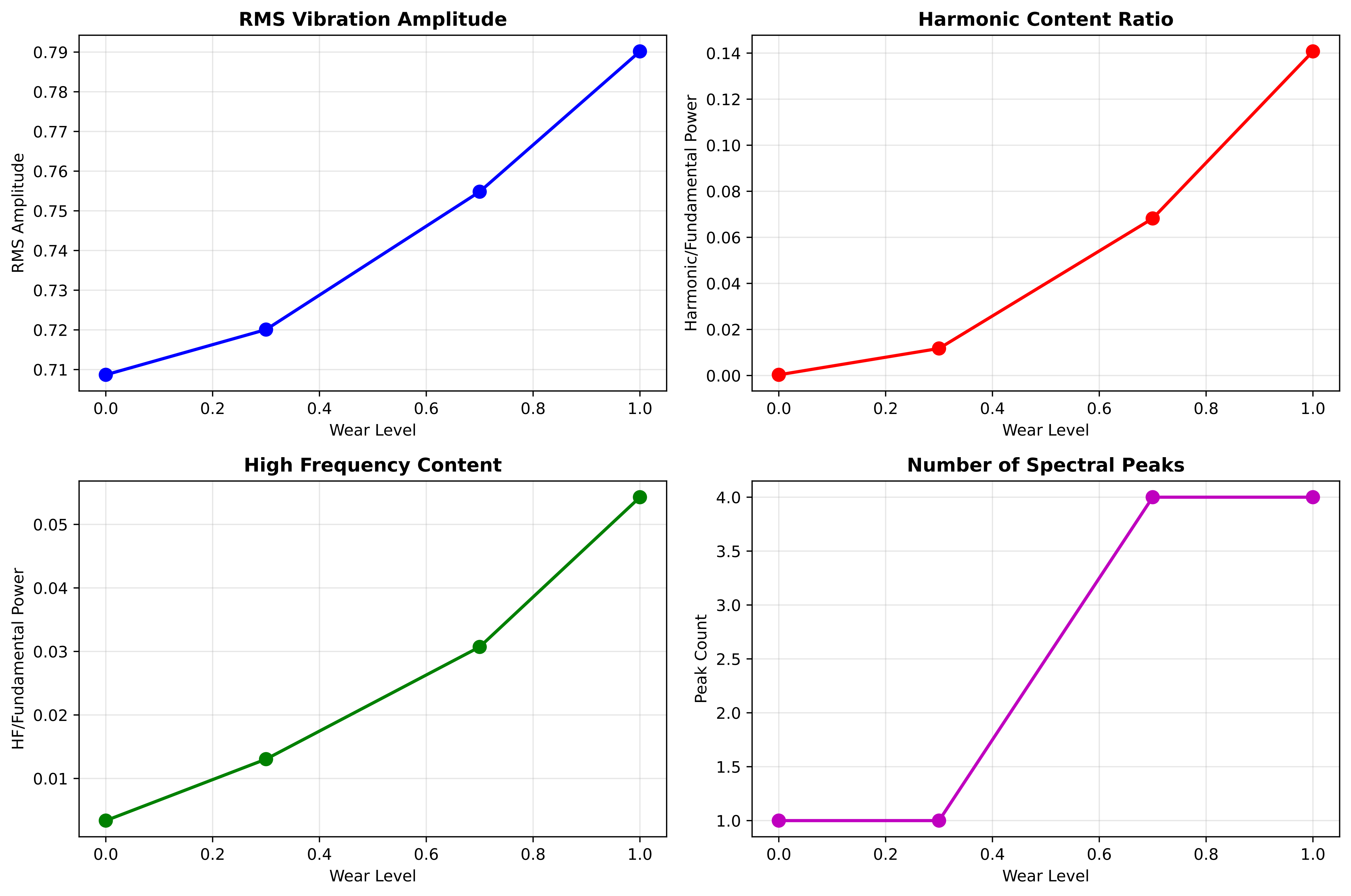

Initial State
Light Wear
Moderate Wear
Severe Wear
Amplitude
Time (s)
0.0
0.1
0.2
0.3
0.4
0.5
−1.5
−1.0
−0.5
0.0
0.5
1.0
1.5

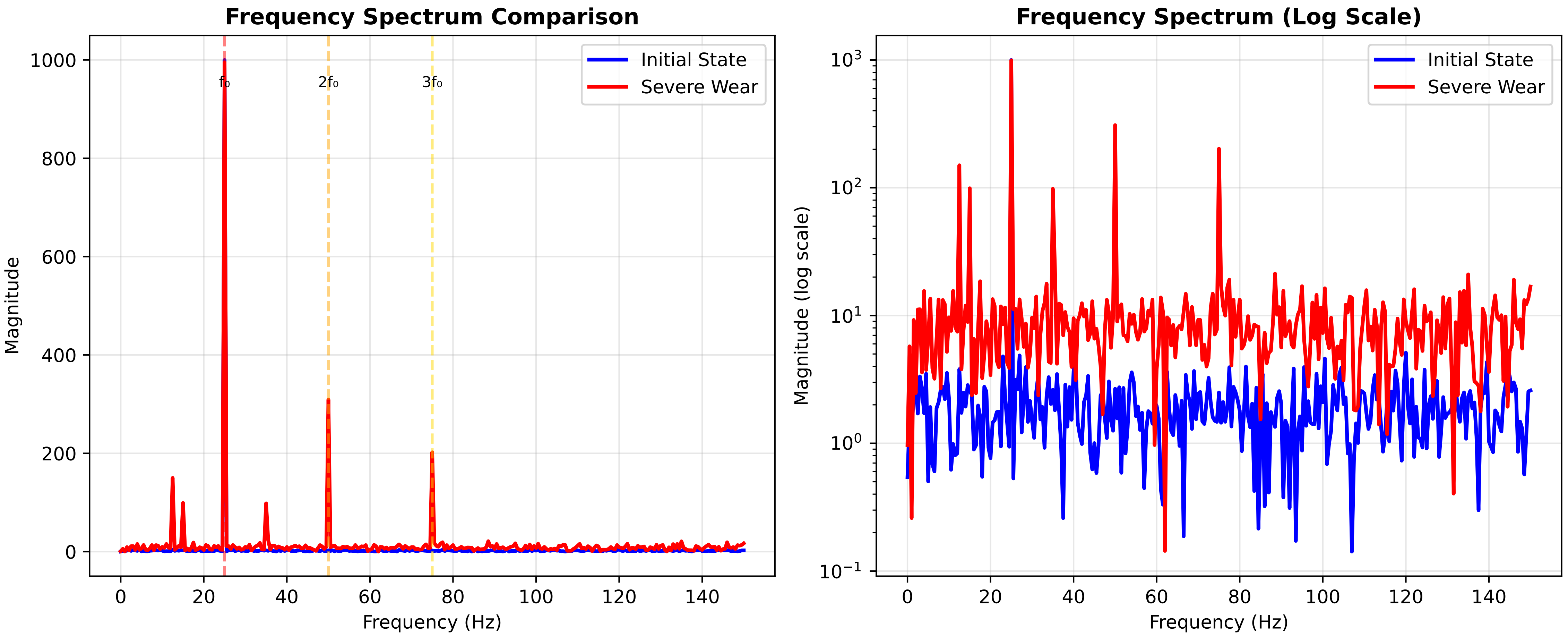


Initial State
Light Wear
Moderate Wear
Severe Wear
f₀
2f₀
3f₀
Magnitude
Frequency (Hz)

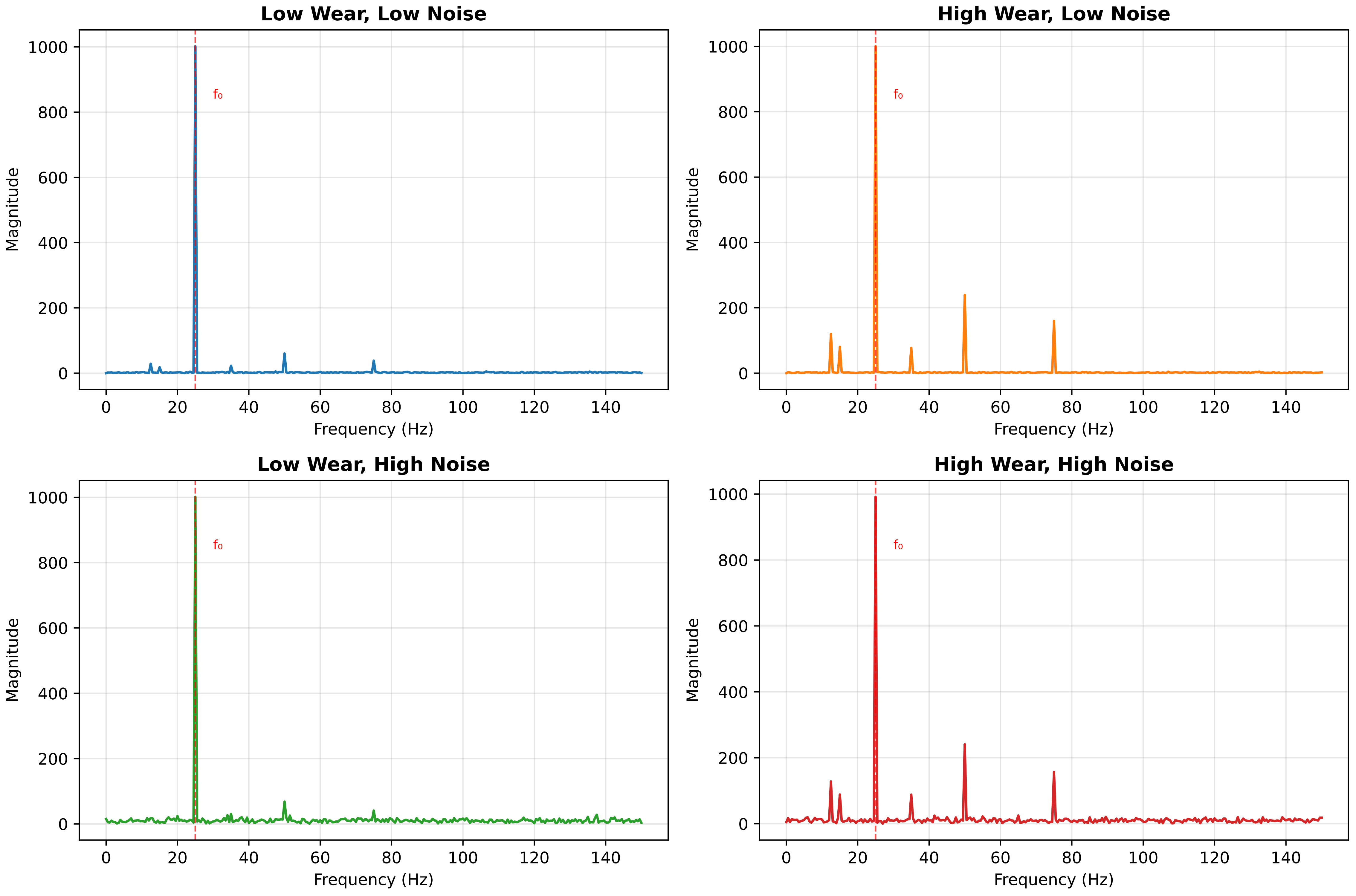


Original Signal
Low-pass Filtered (< 50 Hz)
High-pass Filtered (> 50 Hz)
Band-pass Filtered (40-80 Hz)
Amplitude
Time (s)


RMS Vibration Amplitude
RMS Amplitude
0.71
0.72
0.73
0.74
0.75
0.76
0.77
0.78
0.79
Wear Level
0.0
0.2
0.4
0.6
0.8
1.0
Harmonic Content Ratio
Harmonic/Fundamental Power
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
Wear Level
High Frequency Content
HF/Fundamental Power
0.01
0.02
0.03
0.04
0.05
Wear Level
Number of Spectral Peaks
Peak Count
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Wear Level



Frequency Spectrum Comparison
Initial State
Severe Wear
f₀
2f₀
3f₀
Magnitude
Frequency (Hz)
0
200
400
600
800
1000
0
20
40
60
80
100
120
140
Frequency Spectrum (Log Scale)
Initial State
Severe Wear
Magnitude (log scale)
Frequency (Hz)
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}



Low Wear, Low Noise
High Wear, Low Noise
Low Wear, High Noise
High Wear, High Noise
Magnitude
Frequency (Hz)
f₀
0
200
400
600
800
1000
20
40
60
80
100
120
140

Quantitative Analysis Results

Wear Level	RMS Amplitud	Harmonic Rati	HF Ratio	Peak Count	Fund. Power	Harm. Power	HF Power
0.0	0.7087	0.0003	0.0034	1	374565.2	117.34	1261.04
0.3	0.7201	0.0118	0.0130	1	378452.9	4447.75	4936.42
0.7	0.7548	0.0682	0.0307	4	378575.6	25821.09	11627.11
1.0	0.7902	0.1407	0.0543	4	364164.2	51253.38	19769.29

Computational Methods and Implementation

Analysis Method	Implementation	Key Parameters	Output
Signal Generation	Superposition of sinusoids	Frequencies, amplitudes, noise	Time series x(t)
Preprocessing	Mean removal, windowing	Window type (Hann)	Conditioned signal
FFT Analysis	scipy.fft.fft()	N samples, fs sampling rate	Frequency spectrum
Digital Filtering	Butterworth filters	Order=4, cutoff frequencies	Filtered signals
RMS Calculation	sqrt(mean(x²))	Full signal length	Overall amplitude
Band Power	Sum of |X(f)|² in band	Frequency band limits	Power in band
Peak Detection	scipy.signal.find_peaks()	Height, prominence thresholds	Peak locations

Performance Metrics and Sensitivity Analysis

Metric	Initial→Light	Light→Moderate	Moderate→Severe	Overall Change
RMS Amplitude	1.6%	4.8%	4.7%	11.5%
Harmonic Ratio	3651.5%	480.4%	106.3%	449.3x increase

Frequency Band Analysis and Diagnostic Significance

Frequency Band	Range (Hz)	Physical Significance	Diagnostic Value
Fundamental	23-27	Primary rotation frequency	Baseline reference
Low Harmonics	45-85	2nd and 3rd harmonics	Nonlinear response
Sub-harmonics	10-15	Intermittent contact	Early wear indicator
Sidebands	15-35	Modulation effects	Advanced wear features
High Frequency	100-500	Impulsive events	Surface roughness
Broadband Noise	0-500	Random excitation	Overall degradation

Summary Statistics:

- Total signal length: 2000 samples
- Frequency resolution: 0.50 Hz
- Nyquist frequency: 500.0 Hz
- Maximum detectable frequency: 500.0 Hz