Design of a Cyclic Sliding, Dynamically Loaded Wear Testing Device for the Evaluation of Total Knee Replacement Materials

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Abstract

During normal walking, the relative motion of the human knee involves flexion/extension, anterior/posterior sliding, and medial/lateral rotation. As well, the knee experiences a complex, dynamic loading curve with a peak of up to seven times body weight. However, most wear testing machines that have been used to evaluate total knee replacement materials are unidirectional and/or apply only static force. This thesis presents an alternate wear testing device capable of simulating the most prevalent motions of the knee, and applying physiologically-correct loading to the material interface. By incorporating a CoCr disc, an UHMWPE block, stepping motors, pneumatic components, computer control, and linear tables in an x-y configuration, the device is capable of quickly screening new and alternative materials to UHMWPE before evaluating them on a much more expensive knee simulator. In addition, flexibility of the device allows programming of many different motion and loading configurations permitting materials testing under only certain circumstances, or evaluating the effects on wear of specific motions. Design rationale, development, validation, and future recommendations are presented.

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Abbreviations and Acronyms

A/A	=	Abduction/adduction
ACL	=	Anterior cruciate ligament
AP	=	Anterior/posterior, as in AP sliding
BW	=	Bodyweight
CAD	=	Computer Aided Drawing
CoCr	=	Cobalt chrome
COF	=	Coefficient of friction
F/E	=	Flexion/extension
H.S.	=	Heel strike
I/E	=	Internal/external, or internal/external rotation
OA	=	Osteoarthritis
PCI	=	Peripheral Component Interconnect
PCL	=	Posterior cruciate ligament
PS	=	Posterior stabilizing
T.O.	=	Toe off
TKR	=	Total Knee Replacement or Total Knee Replacements. The term is used to represent both the singular and the plural of the implanted devices.
UHMWPE	=	Ultra-high molecular weight polyethylene
VI	=	Virtual Instrument (Labview™)

Variables

<u>Section 3.2.1.1</u>

A	=	area of the required cylinder
D	=	minimum cylinder diameter (i.e., bore size).
F	=	required maximum force
P	=	maximum input pressure

<u>Section 3.2.3.1</u>

L	=	travel life
V	=	maximum travel rate,

<u>Section 3.2.4</u>

a	=	semi-contact width
E*	=	contact modulus
E_1	=	modulus of material 1
E_2	=	modulus of material 2
ν_1	=	Poisson's ratio of material 1
ν_2	=	Poisson's ratio of material 2
σ_{avg}	=	mean contact stress
σ_{max}	=	maximum contact stress
R	=	effective curvature
P	=	applied load
w	=	width of the CoCr

<u>Section 3.2.7.1</u>

A	=	operating pulses required by the motor
θs	=	motor resolution
f_1	=	starting pulse speed
t_1	=	acceleration period
t_0	=	positioning period
μ	=	coefficient of friction
W	=	maximum load on each rod
R	=	CoCr disc radius
J_o	=	rotor inertia
J_1	=	total inertia
g	=	gravitational constant (386 in/s^2)
J_x	=	inertia of a cylinder

ρ = material density
L = cylinder length
D = cylinder diameter
J_1 = total inertia motor inertias
J_0 = motor inertia

Section 3.2.7.2

A = operating pulses required by the motor
D = cylinder diameter
D_B = ball screw diameter
θs = motor resolution
f_1 = starting pulse speed
f_2 = maximum operating pulse speed
F_0 = pilot pressure load in the table
g = gravitational constant (386 in/s^2)
l = feed per unit
t_0 = positioning period
t_1 = acceleration period
P_B = ball screw pitch
μ = coefficient of friction on the sliding surface
μ_0 = coefficient of friction at the pilot pressure nut
η = ball screw efficiency
W = maximum applied load
J_o = rotor inertia
J_1 = total inertia
J_B = ball screw inertia
J_T = inertia of the table and work
L_B = ball screw length
ρ = material density
T_M = total required torque

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