Project Type Synthesis Homework

Peyton Lettau, Sebastian Hondl, John Robinson, Will McConnell

October 17, 2025

Contents

1 US4509509A: Apparatus for Treating the Joints of the Human Body

1.1 Description

Early CPM concept emphasizing adjustable thigh and calf supports driven by a motorized linkage to provide controlled flexion/extension. Focuses on modular supports and variable range/speed settings to accommodate different patient anatomies and therapy progressions.

1.2 Images

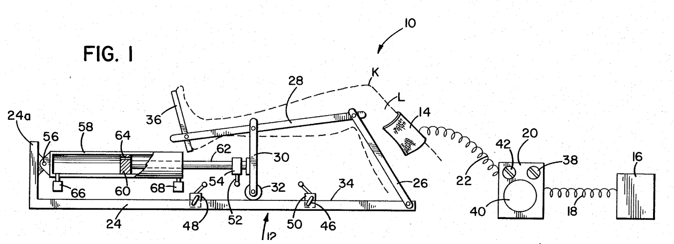

Figure 1: US4509509A apparatus illustrating adjustable thigh/calf supports and drive linkage.

1.3 Mechanism kinematics

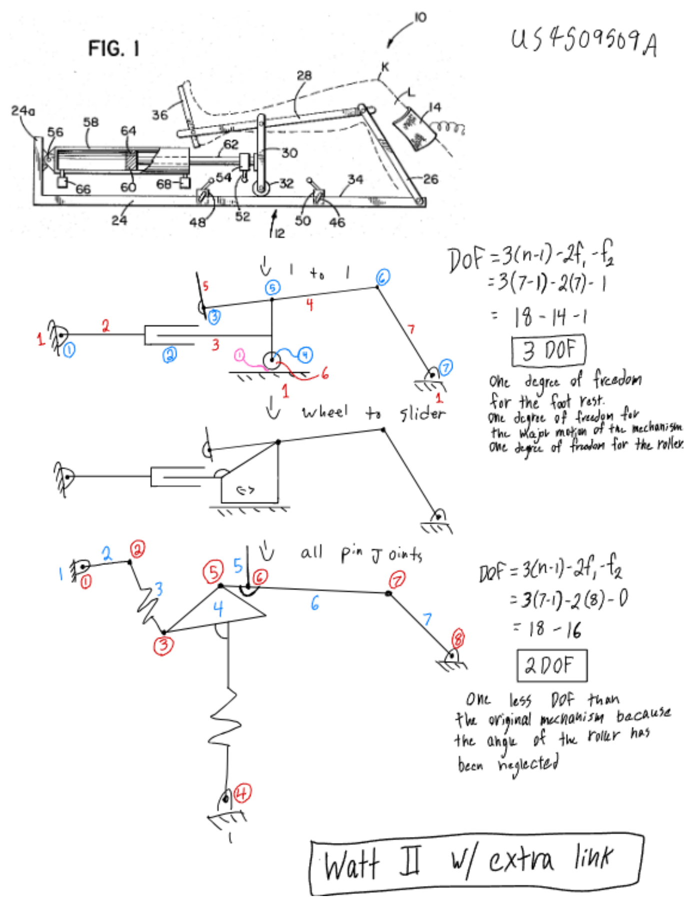

Figure 2: Kinematics diagram for US4509509A apparatus.

1.4 Degrees of Freedom

$$
\begin{aligned}
DOF &= 3(n-1) - 2f_1 - f_2 \\
DOF &= 3(7-1) - 2(8) - 0 \\
DOF &= 2
\end{aligned}
$$

The Mechanism, neglecting the roller position, has 2 degrees of freedom. One for the angle of the foot rest, and another for the main motion of the mechanism. The mechanism is a Watt II with an extra link.

1.5 Observations

This continuous passive motion (CPM) device highlights adjustability. The features include independent thigh and calf supports that are controlled by a motorized linkage. This mechanism consists of rotational joints providing reliable flexing and extending movements while maintaining a simple geometric relationship around limb segments. The design reflects a focus repeatable movement rather than anatomical precision. The ease of setup and durability also make it suitable for rehabilitation clinics. But the fixed-pivot nature of its motion path suggests limited ability to work with all of the ranges of motion of the human knee.

1.6 Opportunities for Improvement

Future iterations could enhance this design by introducing a virtual-pivot or cam-based linkage capable of replicating the knee's natural motion curve. This may improve patient comfort. Adjustment mechanisms and indexing certain stop points could simplify clinician setup and ensure more precise, repeatable motion ranges. The use of lightweight composites or hollow extrusions would also improve transportability and user comfort without sacrificing structural integrity.

2 US4549534A: Leg Exercise Device

2.1 Description

Compact leg exercise mechanism configured for passive knee cycling with an emphasis on home-use practicality. Utilizes a simple linkage and foot support to provide repeatable, low-load flexion/extension with minimal setup.

2.2 Images

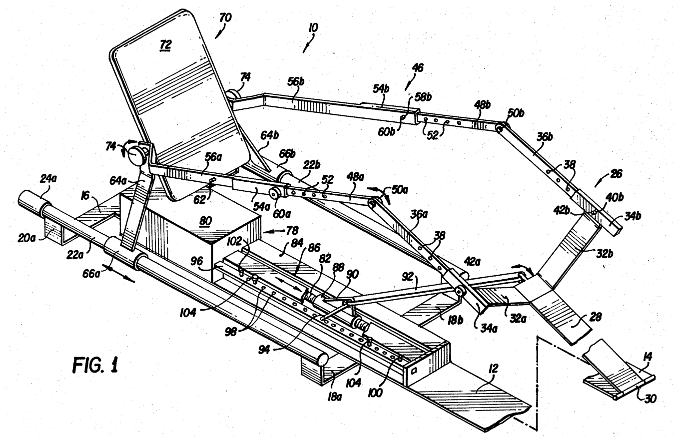

Figure 3: US4549534A leg exercise linkage aimed at repeatable passive motion.

2.3 Mechanism kinematics

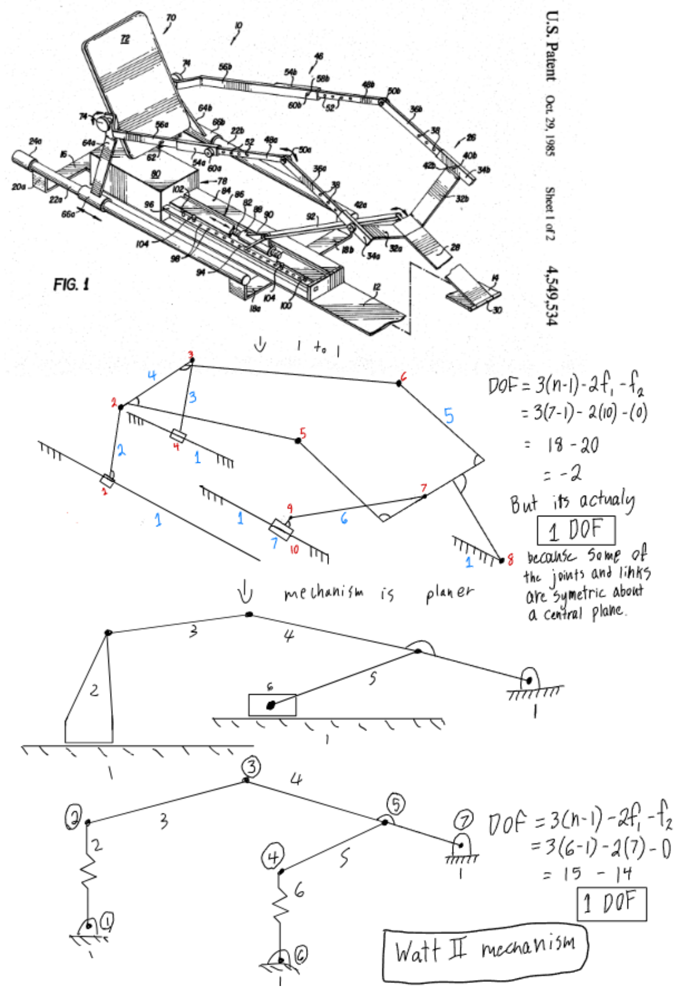

Figure 4: Kinematics diagram for US4549534A leg exercise device.

2.4 Degrees of Freedom

$$DOF = 3(n-1) - 2f_1 - f_2$$
$$DOF = 3(6-1) - 2(7) - 0$$
$$DOF = 1$$

The Mechanism has 1 degree of freedom and is a Watt II mechanism.

2.5 Observations

This design is accessible and compact, offering an easy use mechanical structure intended for home rehabilitation. The device uses a single pivot or short-link mechanism that supports the lower leg and guides it through a prescribed flexion/extension path. The simplicity minimizes cost and setup time, but it also limits the range of motion adjustments. This could potentially lead to suboptimal alignment for users with different leg lengths or limb sizes. Ultimately this design trades accessibility for patient specific needs.

2.6 Opportunities for Improvement

Enhancing adjustability would significantly improve the functionality of this mechanism. Sliding pivots or telescoping linkages could help align the mechanical axis more closely with the user's knee joint, reducing discomfort and improving therapeutic effectiveness. Soft, interchangeable limb supports could further increase comfort and accommodate different patient anatomies.

3 US4566440A: Orthosis for Leg Movement with Virtual Hip Pivot

3.1 Description

Introduces a *virtual hip pivot* to better replicate natural hip–knee kinematics during knee motion, reducing shear and improving alignment. The orthosis geometry helps maintain consistent joint axes throughout the CPM cycle.

3.2 Images

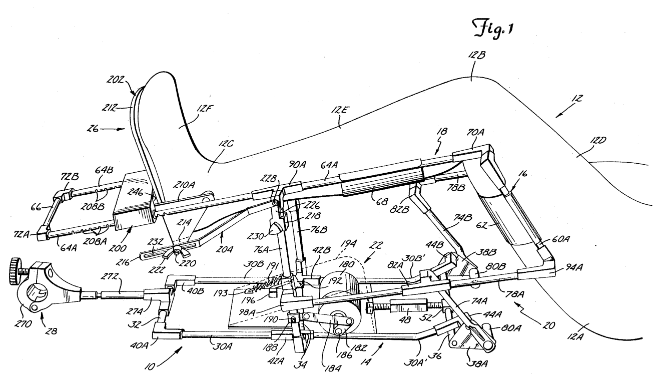

Figure 5: US4566440A orthosis showing geometry for a virtual hip pivot.

3.3 Mechanism kinematics

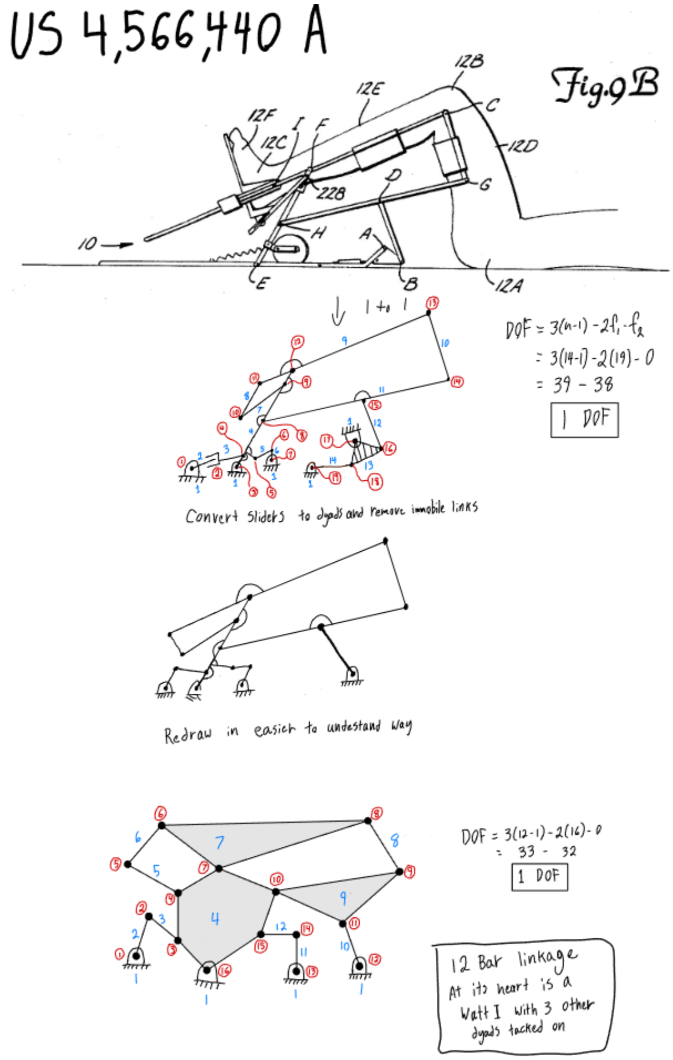

Figure 6: Kinematics diagram for US4566440A orthosis with virtual hip pivot.

3.4 Degrees of Freedom

$$DOF = 3(n-1) - 2f_1 - f_2$$
$$DOF = 3(12-1) - 2(16) - 0$$
$$DOF = 1$$

The Mechanism has 1 degree of freedom and is a Watt I mechanism with several dyads added.

3.5 Observations

This patent represents a very anatomically accurate design by introducing a virtual-pivot mechanism to replicate natural hip motion during lower-limb rehabilitation. Unlike fixed-pivot orthoses, the multi-link arrangement in this design creates an instantaneous center of rotation that migrates during motion, better matching the body's kinematics. The system demonstrates an understanding of motion synthesis and human biomechanics, achieving greater comfort and reduced shear compared to simpler linkages. The complexity of the linkages will only hinder this product for manufacturing costs.

3.6 Opportunities for Improvement

The primary improvements would involve simplifying the geometry while retaining the axis following behavior. Type synthesis techniques could identify an equivalent four bar configuration that reduces parts without sacrificing motion accuracy. Adjustable geometry settings or quick calibration mechanisms could allow clinicians to tailor the virtual-pivot path to individual patients. These refinements would improve manufacturability, reduce weight, and streamline clinical setup, enhancing both performance and practicality.

4 US4974830A: Continuous Passive Motion Device

4.1 Description

Programmable CPM with quick-adjust femoral and tibial cradles and mechanical end-stop management. Emphasizes user-friendly ROM adjustments and reliable actuator control for consistent therapy dosing.

4.2 Images

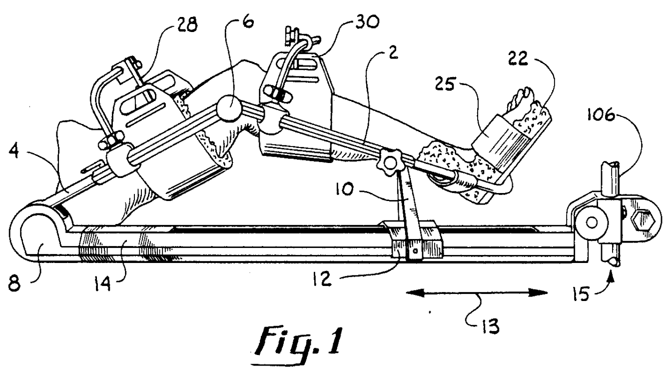

Figure 7: US4974830A CPM with adjustable cradles and end-stop control.

4.3 Mechanism kinematics

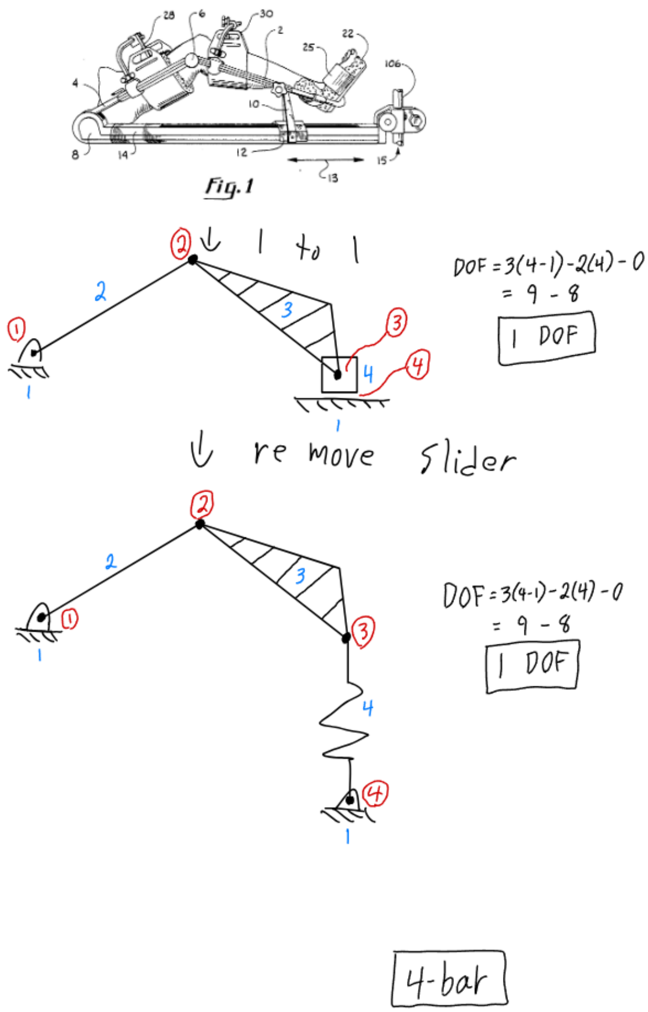

Figure 8: Kinematics diagram for US4974830A continuous passive motion device.

4.4 Degrees of Freedom

$$DOF = 3(n-1) - 2f_1 - f_2$$
$$DOF = 3(4-1) - 2(4) - 0$$
$$DOF = 1$$

The mechanism simplified to a 4 bar linkage with 1 degree of freedom.

4.5 Observations

This patent involves programmable control in the range of motion and repetition cycles, which highlights patient adjustability in those two ways. This mechanism maintains a conventional linkage architecture while also integrating motorized actuation and digital interface elements that are adjustable to clinicians or other users. While this configuration enhances repeatability and safety, the mechanical design remains relatively bulky and dependent on manual adjustment of limb supports.

4.6 Opportunities for Improvement

Future advancements could replace mechanical end stops with electronic soft limits coupled to torque sensors, allowing the system to detect patient resistance and automatically modulate motion for safety and comfort. Incorporating a user-friendly interface with preprogrammed therapy profiles would simplify setup and reduce clinician workload. Additionally, a modular design using lightweight materials could make the unit more portable and suitable for both clinical and home settings. These refinements would bring the design in line with modern ergonomic and usability standards while maintaining the programmability that defines its innovation.

5 US5333604A: Patella Exercising Apparatus

5.1 Description

Targets patellar tracking and anterior knee mechanics, providing controlled patellar motion and load pathways. Highlights isolated patellofemoral mobilization that can complement tibiofemoral CPM to address maltracking concerns.

5.2 Images

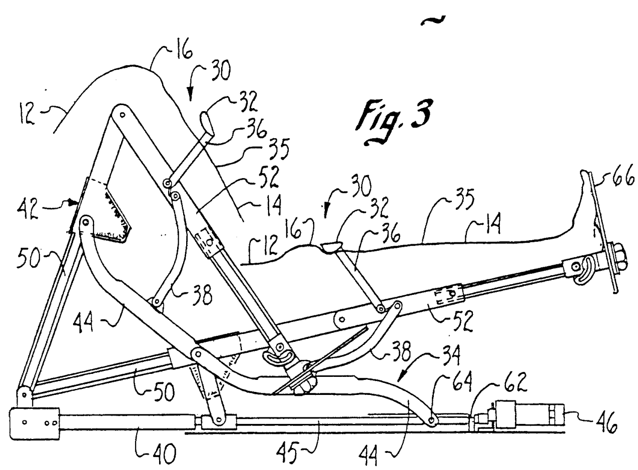

Figure 9: US5333604A apparatus for targeted patellar motion and tracking.

5.3 Mechanism kinematics

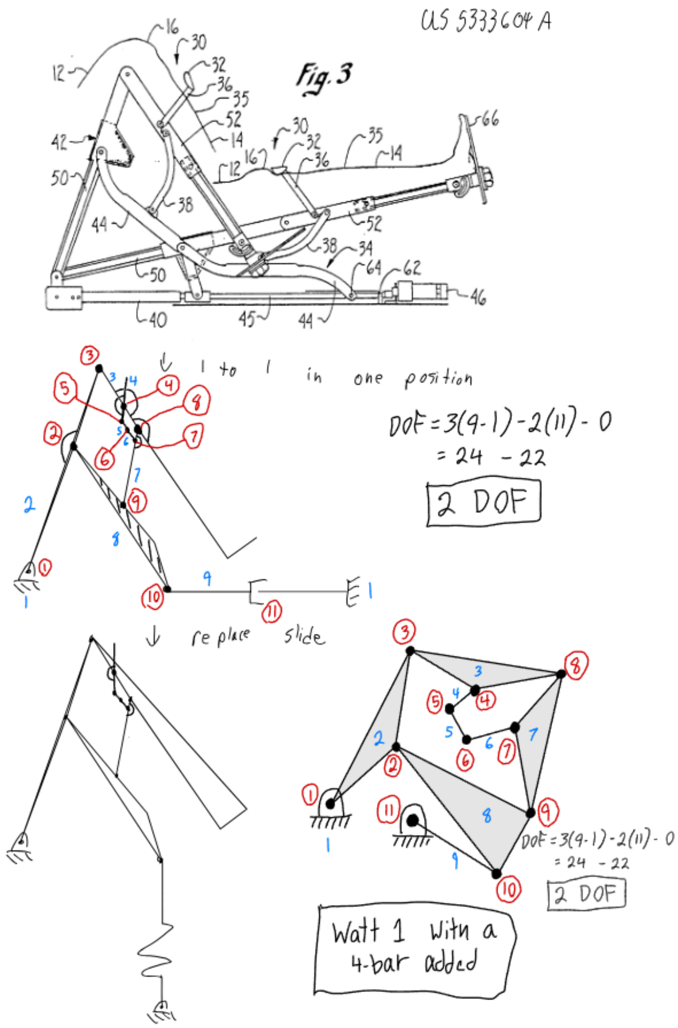

Figure 10: Kinematics diagram for US5333604A patella exercising apparatus.

5.4 Degrees of Freedom

$$DOF = 3(n-1) - 2f_1 - f_2$$
$$DOF = 3(9-1) - 2(11) - 0$$
$$DOF = 2$$

The mechanism has 2 degrees of freedom and is a Watt II mechanism with an added 4 bar linkage.

5.5 Observations

This device focuses on isolated patellar movement to address patellofemoral disorders that other CPM devices ignore. It uses guided track or small linkage that translates and tilts the patella within a controlled range. This mechanical isolation shows a targeted approach to improving tracking and reducing joint pain. As a standalone device it is limited and needs to be used in cooperation with other devices to have full healing of the targeted area.

5.6 Opportunities for Improvement

Incorporating interfaces that emulate the soft-tissue environment could improve comfort and better approximate physiological movement. Adjustable resistance could further customize therapy for different patient needs. These improvements would transform a niche design into a versatile, complementary tool within comprehensive knee rehabilitation systems.

6 US6267735B1: Continuous Passive Motion Device Having a Comfort Zone Feature

6.1 Description

Implements a *comfort zone* deadband that avoids painful end ranges by adapting speed or reversing before irritation thresholds. Designed to increase tolerance and session duration while preserving therapeutic ROM gains.

6.2 Images

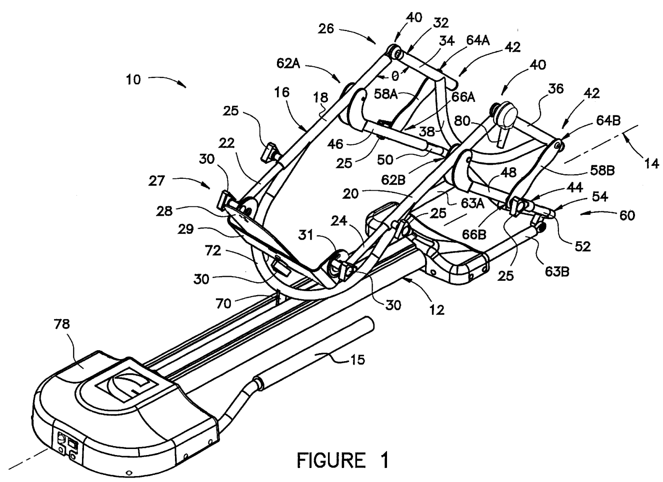

Figure 11: US6267735B1 CPM featuring an adaptive comfort-zone deadband.

6.3 Mechanism kinematics

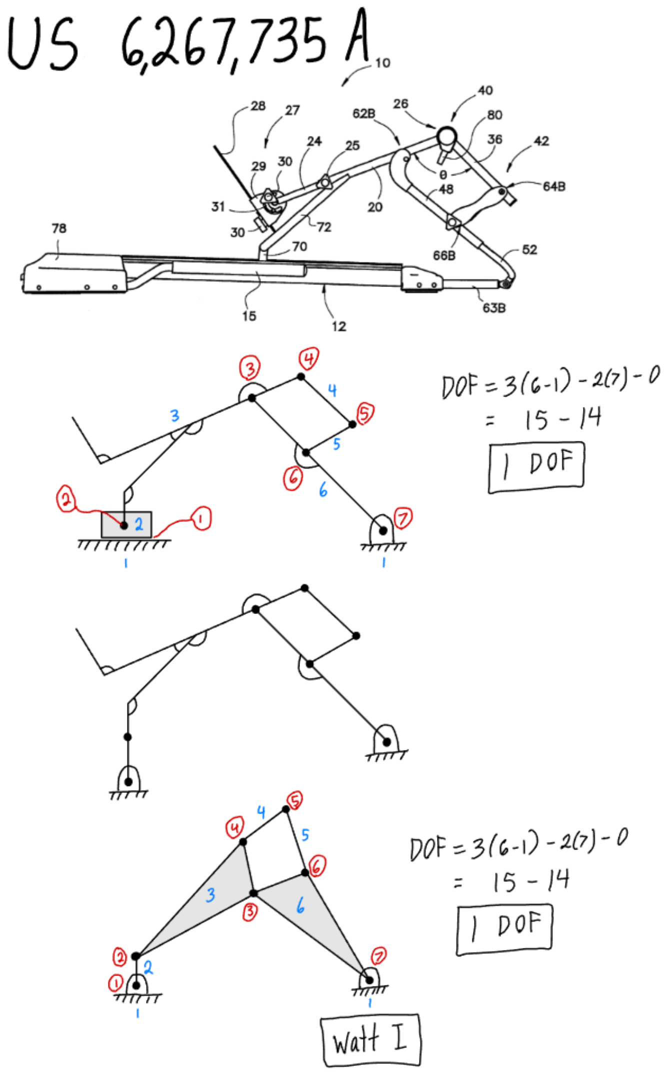

Figure 12: Kinematics diagram for US6267735B1 CPM device with comfort zone feature.

6.4 Degrees of Freedom

$$DOF = 3(n-1) - 2f_1 - f_2$$
$$DOF = 3(6-1) - 2(7) - 0$$
$$DOF = 1$$

The mechanism has 1 degree of freedom and is a Watt I mechanism.

6.5 Observations

This patent has an ergonomic improvement through a "comfort zone" feature. This is an adaptive control system that automatically adjusts motion speed or reverses direction before reaching painful joint limits. By focusing on reducing pain induced muscle guarding, this design enhances compliance and overall rehabilitation outcomes. The control system's sophistication may increase complexity and maintenance requirements compared to simpler mechanical designs.

6.6 Opportunities for Improvement

To further enhance this product development could involve patient specific calibration modes that learn and adapt comfort thresholds over time. This could potentially provide more personalized therapy. Integrating torque and motion sensors with a digital feedback interface would enable real-time monitoring of patient responses. Smooth acceleration and deceleration algorithms could further refine comfort and safety. These improvements would transform the concept from a reactive control system into an intelligent, adaptive therapeutic platform that anticipates and responds to user feedback dynamically.

7 US6325770B1: Device for Producing Continuous Passive Motion

7.1 Description

Mechanical drive (e.g., cam/gear) tuned to follow a knee-like path, aiming for physiologic tibiofemoral motion. Focuses on smooth kinematics and robust transmission to reduce backlash and improve comfort.

7.2 Images

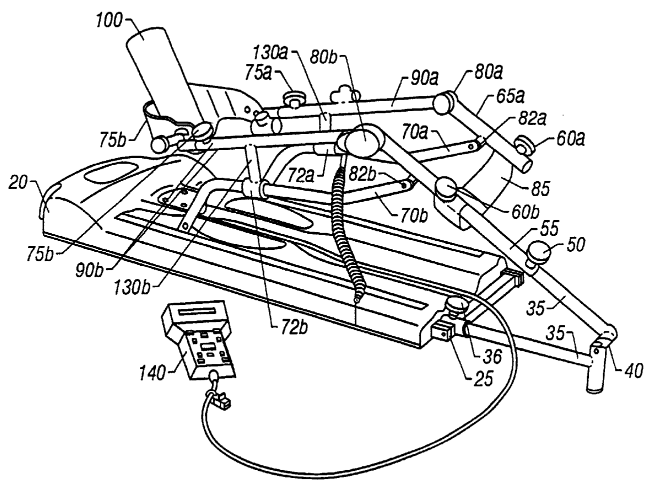

FIG. 3

Figure 13: US6325770B1 transmission tuned for knee-like motion paths.

7.3 Mechanism kinematics

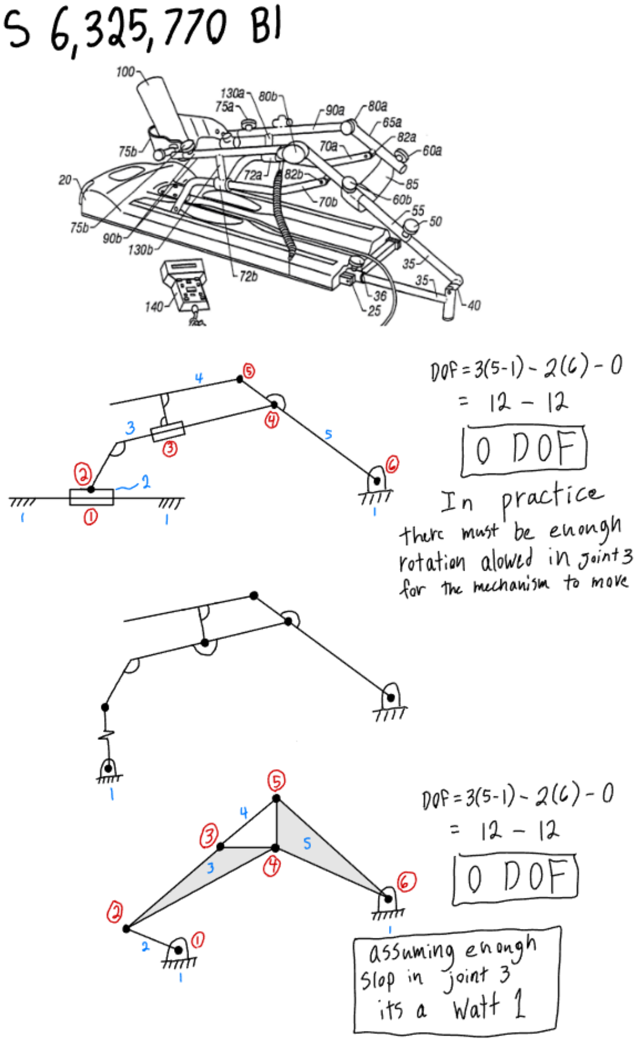

Figure 14: Kinematics diagram for US6325770B1 device for producing continuous passive motion.

7.4 Degrees of Freedom

$$DOF = 3(n-1) - 2f_1 - f_2$$
$$DOF = 3(5-1) - 2(6) - 0$$
$$DOF = 0$$

The mechanism has 0 degrees of freedom according to our analysis, though there may be details missing from the drawing. We assume there must be rotation at joint 3 to allow mechanism 1 degree of freedom.

7.5 Observations

This design uses cam and gear transmissions to generate a motion profile that better mimics the natural kinematics of the knee joint. Unlike traditional rotary or linear drives, the cam mechanism allows nonuniform angular velocity and displacement, producing a smoother, more physiologically accurate movement. The use of tuned cams also helps reduce mechanical backlash and improve motion precision. The fixed cam geometry may limit adaptability across patients with different anatomical characteristics or therapeutic requirements.

7.6 Opportunities for Improvement

One promising enhancement would be the implementation of interchangeable or adjustable cam profiles to accommodate varying knee geometries and rehabilitation goals. Incorporating modern materials and precision machining could reduce weight and wear while maintaining the smooth motion advantage. Additionally, compliant joints or flexible couplings could be integrated to absorb small misalignments, minimizing shear at the patient interface. Together, these refinements would maintain the benefits of the cam-driven approach while improving adaptability and patient-specific performance.

8 US5252102A: Electronic Range of Motion Apparatus for Orthosis/Prosthesis/CPM

8.1 Description

Integrates electronic ROM sensing and feedback into an orthotic/CPM framework. Enables measurement-driven progression, alarms for unsafe limits, and data logging for clinical assessment.

8.2 Images

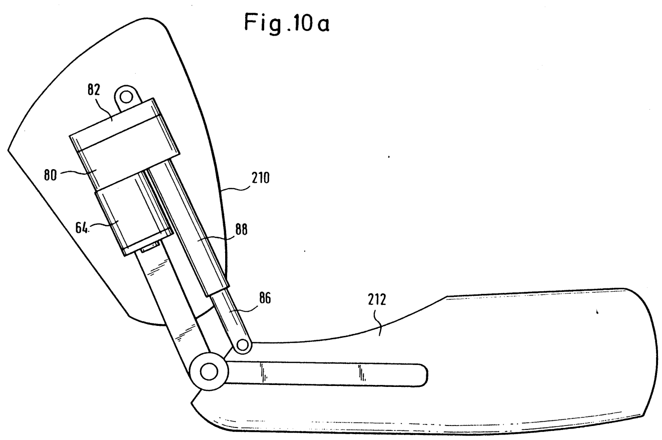

Figure 15: US5252102A apparatus with integrated electronic ROM sensing.

8.3 Mechanism kinematics

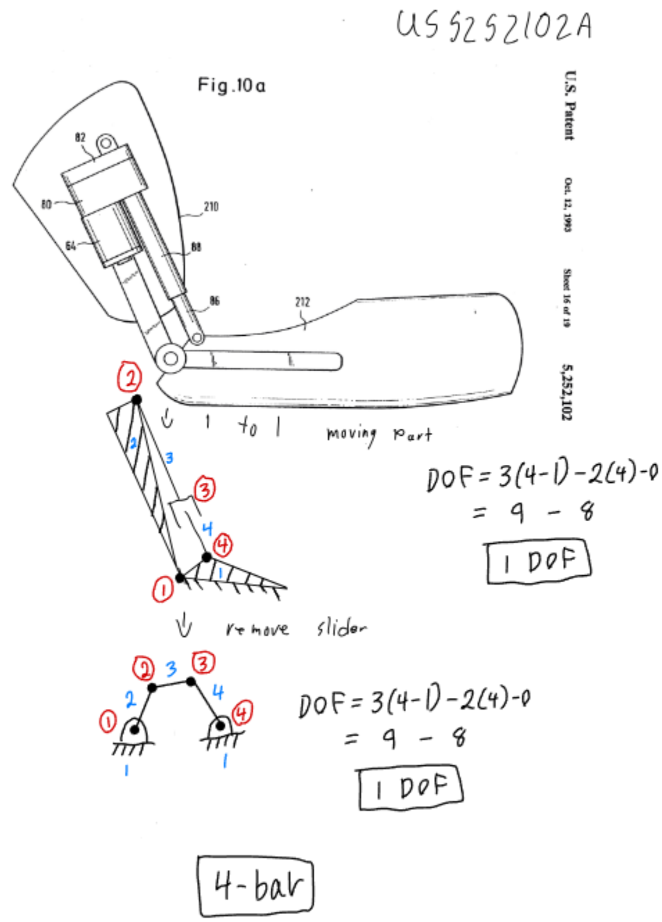

Figure 16: Kinematics diagram for US5252102A electronic range of motion apparatus.

8.4 Degrees of Freedom

$$DOF = 3(n-1) - 2f_1 - f_2$$
$$DOF = 3(4-1) - 2(4) - 0$$
$$DOF = 1$$

The mechanism has 1 degree of freedom and is a 4 bar linkage.

8.5 Observations

This patent integrates electronic sensing and feedback into a traditional CPM system, marking a transition toward data-driven rehabilitation. By recording range of motion and detecting resistance, the device enables clinicians to monitor patient progress quantitatively and ensure motion remains within safe limits. Mechanically, it retains a conventional linkage structure but augments it with position and torque sensors that provide valuable diagnostic data.

8.6 Opportunities for Improvement

Expanding this concept with wireless data transfer and cloud-based monitoring would modernize its functionality, allowing clinicians to review therapy sessions remotely. Pairing the sensing system with adaptive control could enhance safety and personalization. The particular advancements here preserve the patent's original focus on measurement and feedback while greatly improving accessibility and interactivity.

9 US4492222A: Knee Exercise Machine

9.1 Description

Adjustable axis alignment between femoral and tibial supports with a stable footplate to promote consistent knee pivoting. Emphasizes structural simplicity and robust construction for repeated clinical use.

9.2 Images

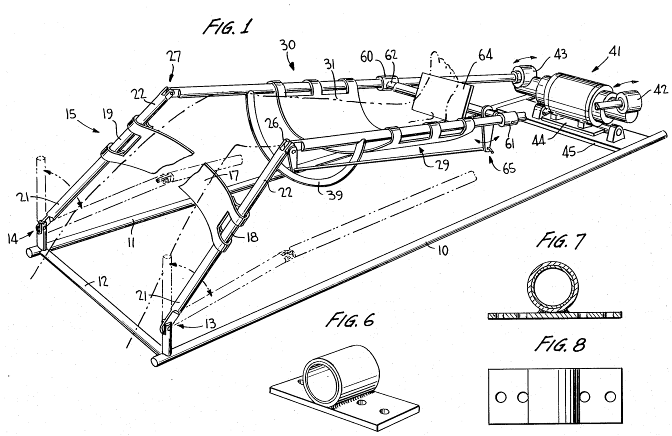

Figure 17: US4492222A knee exercise machine with adjustable axis alignment.

9.3 Mechanism kinematics

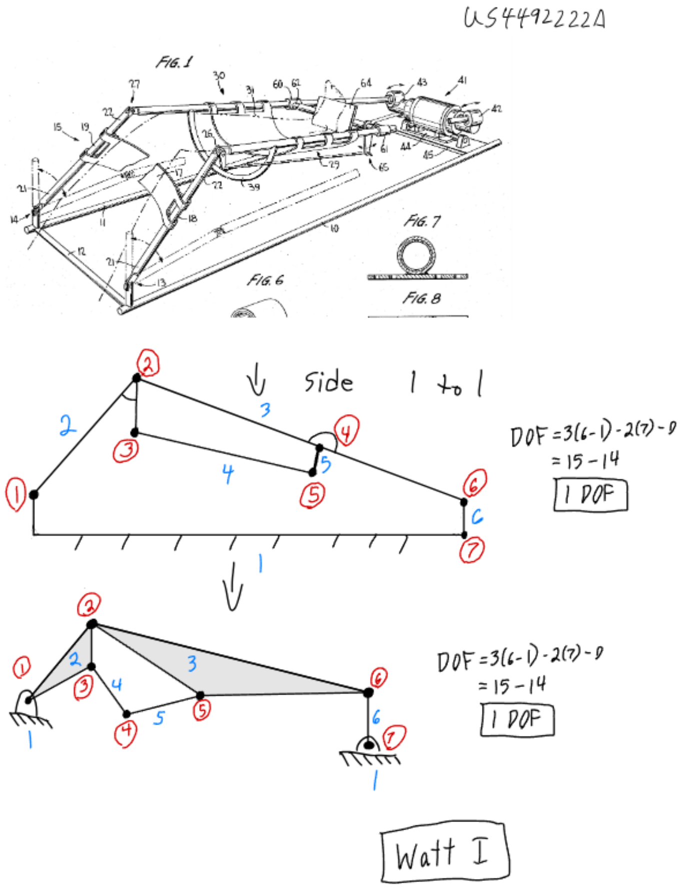

Figure 18: Kinematics diagram for US4492222A knee exercise machine.

9.4 Degrees of Freedom

$$
\begin{aligned}
DOF &= 3(n-1) - 2f_1 - f_2 \\
DOF &= 3(6-1) - 2(7) - 0 \\
DOF &= 1
\end{aligned}
$$

The mechanism has 1 degree of freedom and is a Watt I mechanism.

9.5 Observations

This patent shows a mechanical knee exercise machine with a focus on axis alignment between femoral and tibial supports. The system is adjustable, allowing clinicians to fine tune the mechanical pivot to match individual anatomy. This capability reduces off axis loading and enhances the accuracy of joint motion replication. The bulk and manual adjustment requirements may hinder usability in nonclinical environments.

9.6 Opportunities for Improvement

Streamlining the adjustment process through indexed or self-aligning pivots could make setup faster and more intuitive, minimizing the potential for misalignment. Introducing foldable or modular components would further expand its usability beyond clinic settings. These changes would modernize the design while preserving its core advantage of accurate joint axis alignment.

10 US10272291B2: Knee Flexion and Extension Therapy Device and Method of Use

10.1 Description

Modern therapy platform with modular brace interfaces and sensor-ready architecture for tracking compliance and motion. Highlights portability and user-centric controls to support clinic-to-home continuity.

10.2 Images

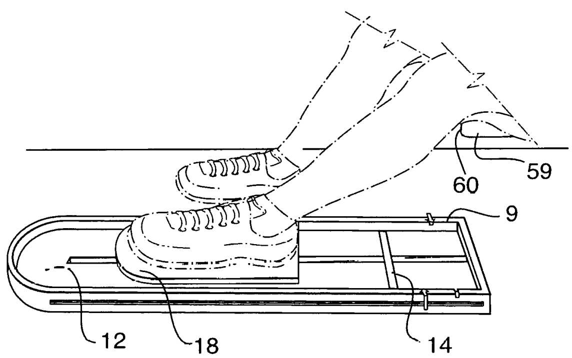

FIG. 8

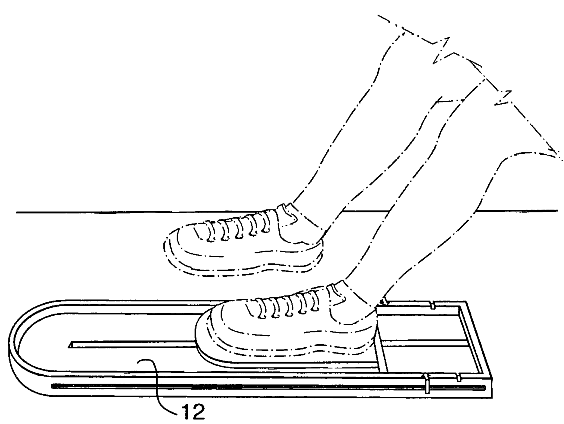

FIG.9

Figure 19: US10272291B2 modern therapy platform for knee flexion/extension.

10.3 Mechanism kinematics

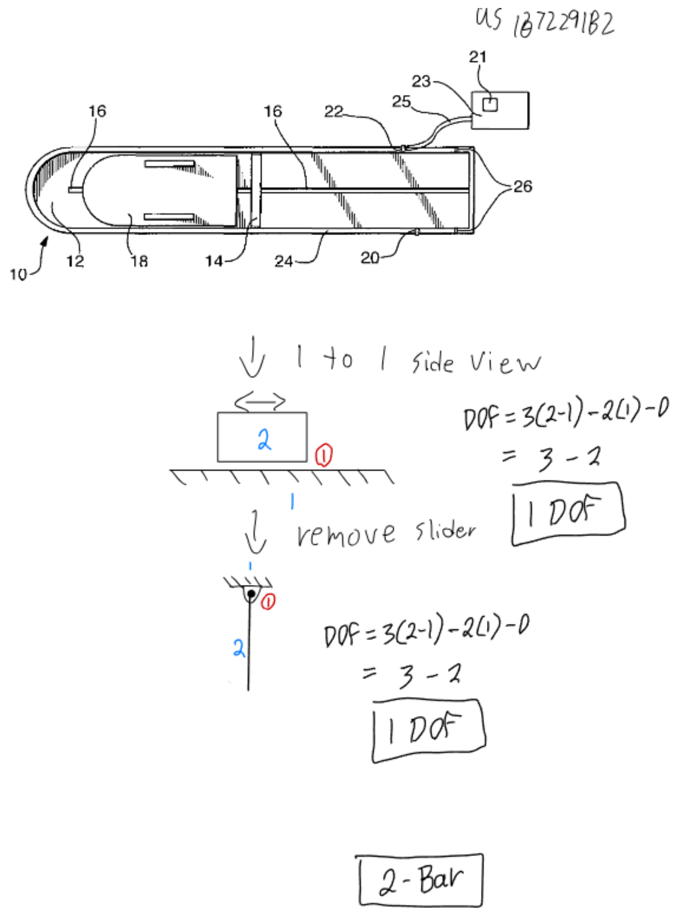

Figure 20: Kinematics diagram for US10272291B2 knee flexion and extension therapy device.

10.4 Degrees of Freedom

$$DOF = 3(n-1) - 2f_1 - f_2$$
$$DOF = 3(2-1) - 2(1) - 0$$
$$DOF = 1$$

The mechanism is a simple slider mechanism with 1 degree of freedom.

10.5 Observations

This patent reflects a significant evolution in CPM technology, integrating digital sensors, modular components, and portable design features to accommodate both clinical and at home use. The mechanism combines traditional linkage motion with embedded encoders or inertial sensors for real time tracking of angular position and speed. The use of lightweight materials and adjustable limb supports demonstrates attention to ergonomics and patient comfort. The system's modularity also suggests compatibility with mobile data systems for progress monitoring. The inclusion of multiple electronic subsystems introduces potential reliability and power management challenges that earlier mechanical designs avoided.

10.6 Opportunities for Improvement

Enhancements could focus on improving usability and energy efficiency through better battery management and intuitive software interfaces. Simplified clinician presets and patient guided setup routines could reduce user error while maintaining precise control. Integrating cloud connectivity for data storage and remote supervision would further align the device with current trends in tele-rehabilitation. These refinements would enhance the balance between technological sophistication and practical reliability, ensuring the device remains accessible while offering advanced monitoring and control.

11 US4603687A: Continuous Passive Motion Orthopedic Device

11.1 Description

Counterbalanced support arms with a motorized actuator and alignment aids to minimize off-axis loads. Designed for steady, repeatable cycles with straightforward mechanical adjustments.

11.2 Images

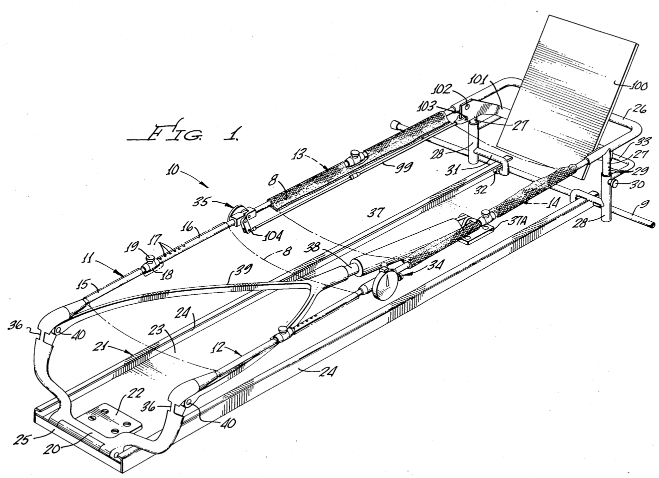

Figure 21: US4603687A CPM with counterbalanced arms and alignment aids.

11.3 Mechanism kinematics

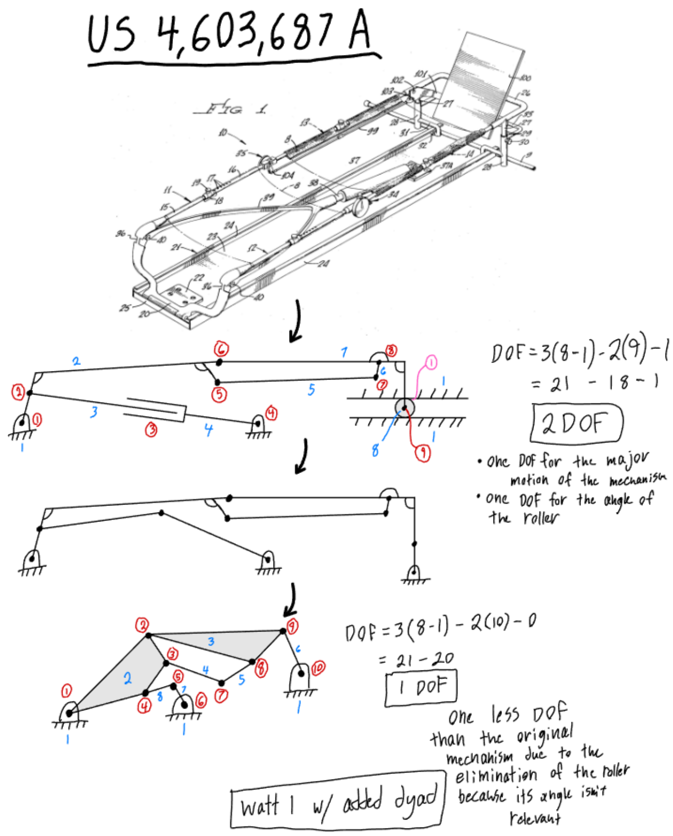

Figure 22: Kinematics diagram for US4603687A continuous passive motion orthopedic device.

11.4 Degrees of Freedom

$$DOF = 3(n-1) - 2f_1 - f_2$$
$$DOF = 3(8-1) - 2(10) - 0$$
$$DOF = 1$$

The mechanism, neglecting the roller rotation, has 1 degree of freedom and is a Watt I mechanism with an added dyad.

11.5 Observations

This design incorporates counterbalanced support arms to reduce the torque demands on the drive motor and minimize the physical strain on the patient. The use of balanced linkages allows smoother operation and consistent motion profiles across a range of limb weights, representing a thoughtful mechanical optimization. By improving load distribution, the design also enhances safety and reduces actuator wear. However, its relatively large frame and reliance on rigid structural components make the system heavy and less adaptable for different rehabilitation environments.

11.6 Opportunities for Improvement

Replacing bulky counterweights with compact spring based or pneumatic balancing systems could significantly reduce size and weight while maintaining equilibrium. Introducing adjustable counterbalance calibration would enable use across a wider range of patients without manual recalibration.

Furthermore, using advanced lightweight alloys or composite arms could further reduce inertia, improving responsiveness and portability. These updates would retain the patent's core mechanical advantage while modernizing its form factor and usability.

12 US5239987A: Anatomically Correct Continuous Passive Motion Device for a Limb

12.1 Description

Axis-following mechanism intended to accommodate the knee's migrating instantaneous center of rotation. Reduces misalignment-induced shear by adapting the motion path to a more anatomic "J-curve".

12.2 Images

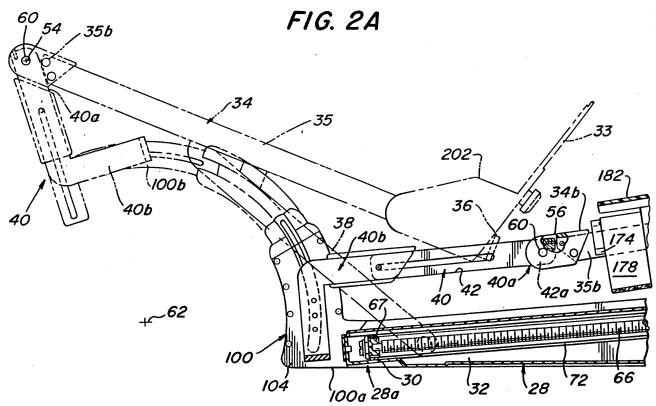

Figure 23: US5239987A device adapting to the knee's shifting rotation center.

12.3 Mechanism kinematics

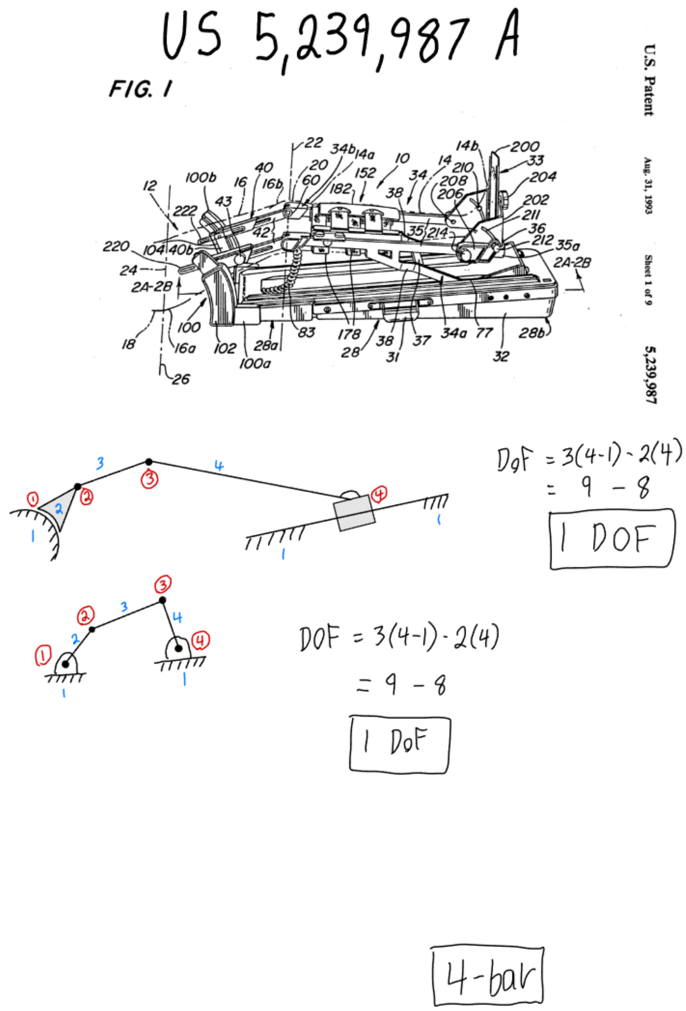

Figure 24: Kinematics diagram for US5239987A anatomically correct continuous passive motion device.

12.4 Degrees of Freedom

$$DOF = 3(n-1) - 2f_1 - f_2$$
$$DOF = 3(4-1) - 2(4) - 0$$
$$DOF = 1$$

The mechanism has 1 degree of freedom and is a 4 bar linkage.

12.5 Observations

This patent focuses on replicating the knee's natural instantaneous center of rotation by employing an axis-following or "J-curve" linkage path. The design represents a sophisticated application of kinematic synthesis to orthopedic rehabilitation, allowing more anatomically accurate motion that reduces shear forces and enhances comfort. Such precision comes at the cost of mechanical complexity, requiring tight tolerances and careful calibration. While the anatomical fidelity is a major advancement, manufacturing difficulty and setup sensitivity likely limited its widespread adoption.

12.6 Opportunities for Improvement

Future designs could pursue simplified link arrangements. An optimized four-bar or compliant mechanism that preserves the J-curve motion with fewer components is one line of thinking. Adjustable link geometries could allow clinicians to tune motion profiles to individual patients without custom fabrication. Integrating sensors to verify axis alignment during setup could further improve reliability. These refinements would maintain the device's biomechanical accuracy while improving manufacturability and ease of use, making anatomically correct CPM more practical for routine clinical application.

13 US4546763A: Continuous Passive Motion Method and Apparatus

13.1 Description

Claims both apparatus and therapy parameters, including programmable cycle timing, dwell at end range, and progressive ROM. Focuses on protocolization of CPM dosing alongside reliable mechanical delivery.

13.2 Images

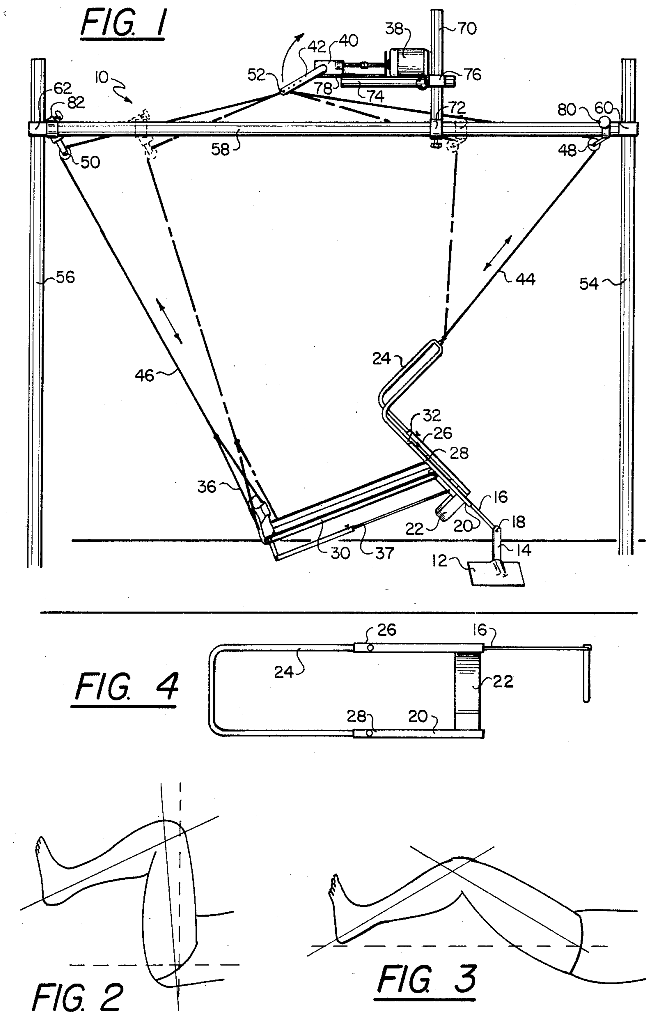

Figure 25: US4546763A apparatus and protocol emphasizing programmable CPM dosing.

13.3 Mechanism kinematics

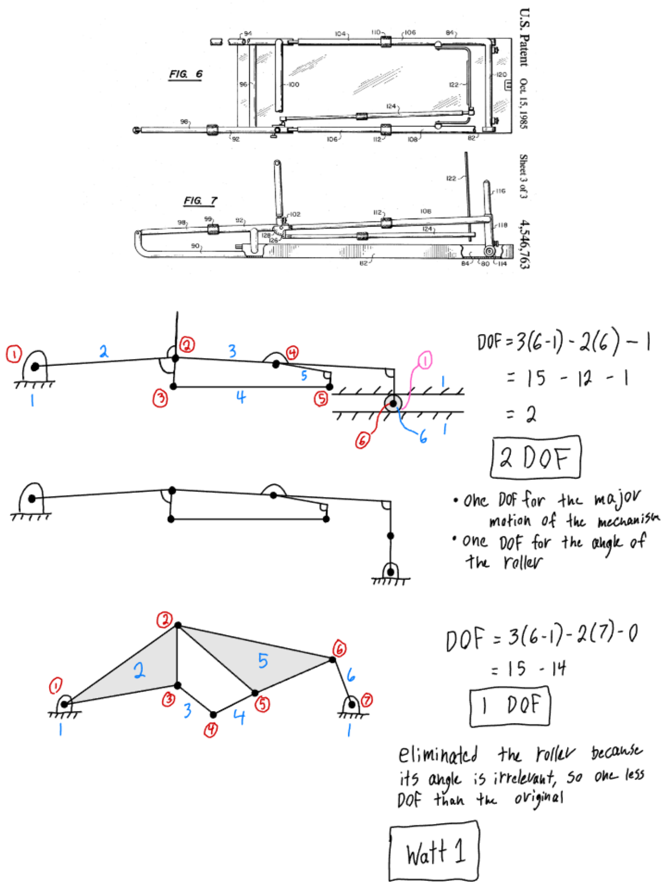

Figure 26: Kinematics diagram for US4546763A continuous passive motion method and apparatus.

13.4 Degrees of Freedom

$$DOF = 3(n-1) - 2f_1 - f_2$$
$$DOF = 3(6-1) - 2(7) - 0$$
$$DOF = 1$$

The mechanism has 1 degree of freedom and is a Watt I mechanism.

13.5 Observations

This patent combines a mechanical device with defined therapeutic protocols, emphasizing programmable timing, dwell intervals, and progressive range of motion. It marks a shift toward evidence-based rehabilitation through repeatable motion dosing. Mechanically, it employs a conventional motor driven linkage system, but the innovation lies in its programmable controller, which enables consistent execution of therapy regimens. This hybrid of engineering and clinical insight underscores the importance of standardized therapy but still depends heavily on manual input and static programming.

13.6 Opportunities for Improvement

Integrating adaptive control algorithms that respond to patient feedback such as pain inputs, motion resistance, or compliance would evolve the system into a truly intelligent therapy platform. Cloud based storage and analytics could allow clinicians to monitor outcomes and adjust protocols remotely. User friendly software interfaces with built in clinical presets would further simplify setup and improve adherence. By modernizing the control strategy while maintaining the patent's commitment to repeatable, evidence based motion, future designs could bridge the gap between mechanical precision and personalized therapy.

14 US4637379A: Device for Imparting Continuous Passive Motion to Leg Joints

14.1 Description

Mechanical device designed to provide continuous passive motion specifically targeting leg joint mobility. Emphasizes controlled articulation of knee and hip joints through automated motion cycles to maintain joint flexibility and prevent stiffness.

14.2 Images

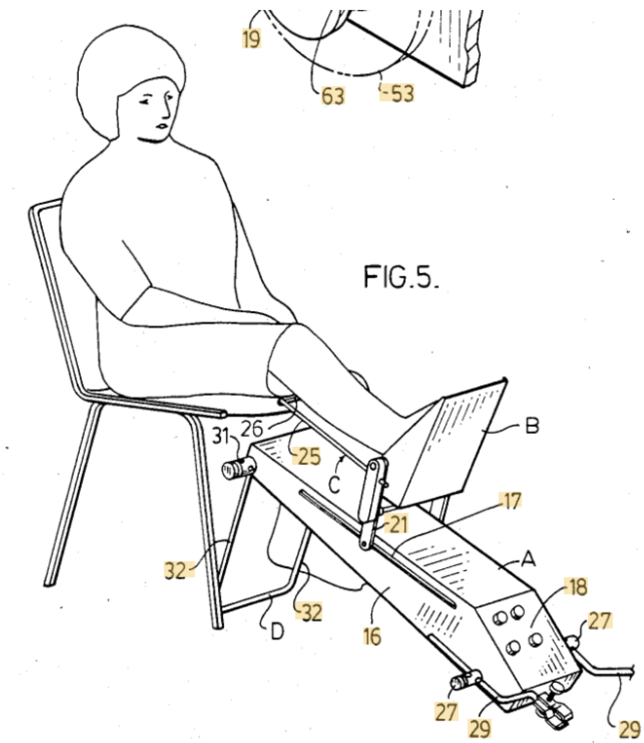

Figure 27: US4637379A device for continuous passive motion of leg joints.

14.3 Mechanism kinematics

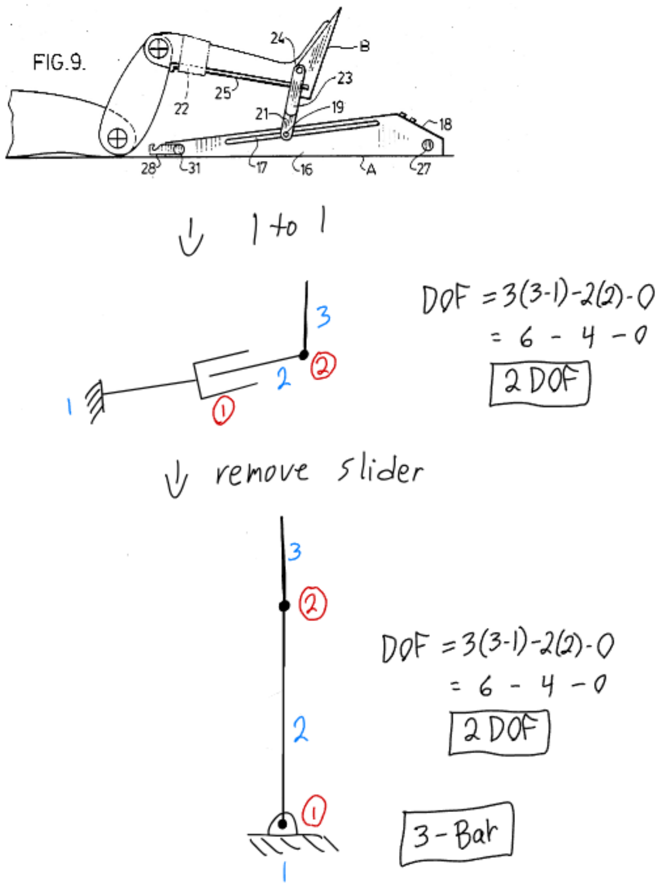

Figure 28: Kinematics diagram for US4637379A device for imparting continuous passive motion to leg joints.

14.4 Degrees of Freedom

$$DOF = 3(n-1) - 2f_1 - f_2$$
$$DOF = 3(3-1) - 2(2) - 0$$
$$DOF = 2$$

The mechanism is simply a 3 bar linkage with 2 degrees of freedom.

14.5 Observations

This patent discloses a hybrid actuation structure in which a motor driven carriage executes linear reciprocation along a base, and that motion is translated into combined longitudinal and arcuate displacement of a foot rest. The design enables selectively mobilizing the hip and knee together (with the ankle held) or mobilizing the ankle alone (with knee/hip fixed) by using a spacing or locking frame to change the pivot constraints. By altering the path constraints, it switches between two modes of articulation. closed-loop control to regulate stroke length independent of carriage position. The device also provides adjustable supports and mounting legs to align the base relative to the patient. Despite this flexibility, its reliance on a rigid frame and discrete mode switching may limit smooth transitions and patient comfort under varying anatomical geometries.

14.6 Opportunities for Improvement

One opportunity is to replace the discrete mode-switching between joint combinations with a continuously adaptive kinematic coupling. For example, a mechanism that gradually shifts the pivot locus rather than fully locking or unlocking frames. This would smooth transitions and better accommodate patient specific joint behavior.

15 US4665899A: Apparatus for Articulating the Knee and Hip Joints

15.1 Description

Dual-joint articulation system that simultaneously addresses both knee and hip joint motion. Designed to maintain proper biomechanical relationships between adjacent joints during passive motion therapy, ensuring coordinated movement patterns.

15.2 Images

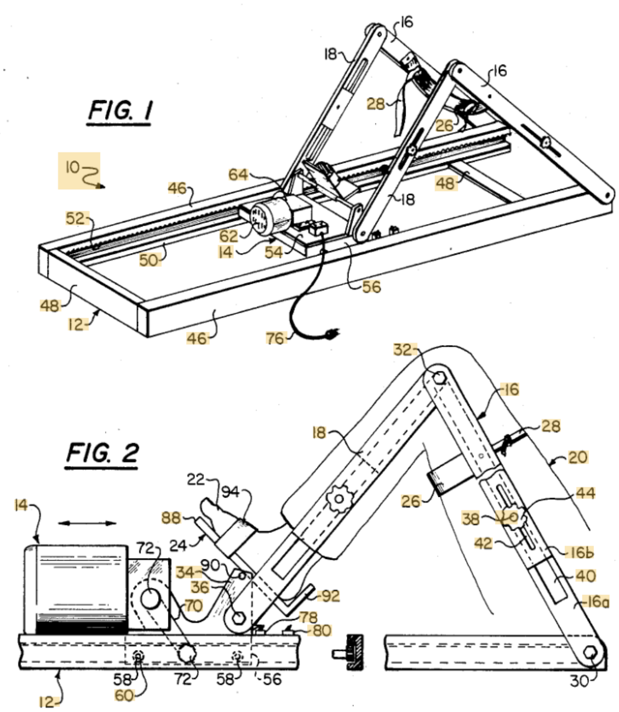

Figure 29: US4665899A apparatus for coordinated knee and hip joint articulation.

15.3 Mechanism kinematics

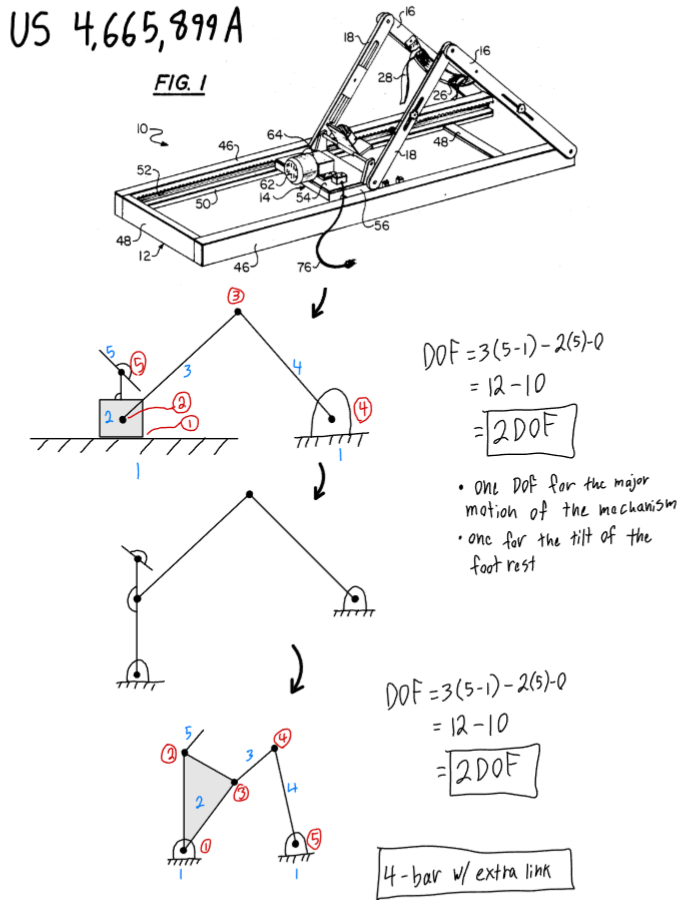

Figure 30: Kinematics diagram for US4665899A apparatus for articulating the knee and hip joints.

15.4 Degrees of Freedom

$$DOF = 3(n-1) - 2f_1 - f_2$$
$$DOF = 3(5-1) - 2(5) - 0$$
$$DOF = 2$$

The mechanism is a 4 bar linkage with an extra link added.

15.5 Observations

This patent describes a dual arm linkage system in which a carriage reciprocates along a fixed base, with a first pair of arms pivoting from the base and a second pair connecting to the carriage, creating a four bar like structure spanning the leg. The foot is mounted on a pivoting support on the carriage, and the thigh is cradled by supports between the first arms. Reciprocal motion of the carriage articulates both the knee and hip simultaneously in a coordinated path. The device also includes adjustable arm lengths (via sliding members) to accommodate different thigh lengths and patient sizes. The floating coupling of the thigh cradle to the arms allows relative rotational movement, which helps reduce misalignment stress. Its structural approach is robust and better suited to capture the coupled kinematics of hip knee motion than purely single pivot designs.

15.6 Opportunities for Improvement

The adjustable arm length elements could be enhanced with indexable detents or tool-less locking to speed up clinical configuration. The floating coupling could be further refined with compliant joints or flexure elements to absorb minor misalignment without force spikes. Finally, advancing the actuation system with a smooth motion profile (cam or variable transmission) instead of straight reciprocity could reduce abrupt transitions and better mimic physiological joint movement.

16 WO2011119902A1: Continuous Passive Motion Device

16.1 Description

International patent application describing a modern continuous passive motion device with enhanced control systems and patient comfort features. Represents contemporary approaches to CPM therapy with improved user interface and adaptive motion profiles.

16.2 Images

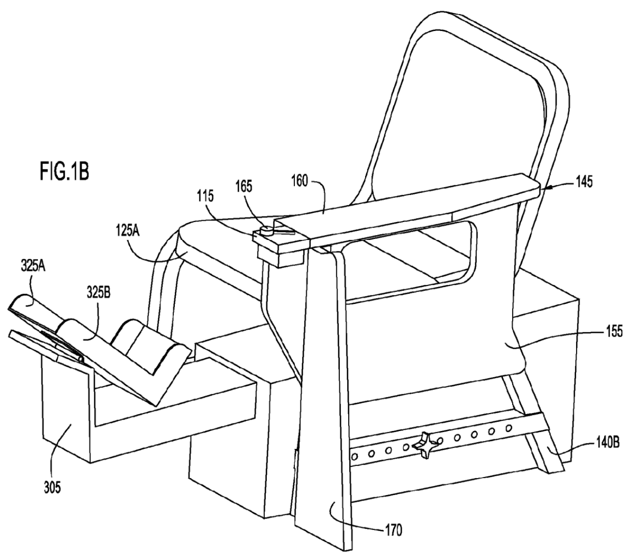

Figure 31: WO2011119902A1 modern continuous passive motion device.

16.3 Mechanism kinematics

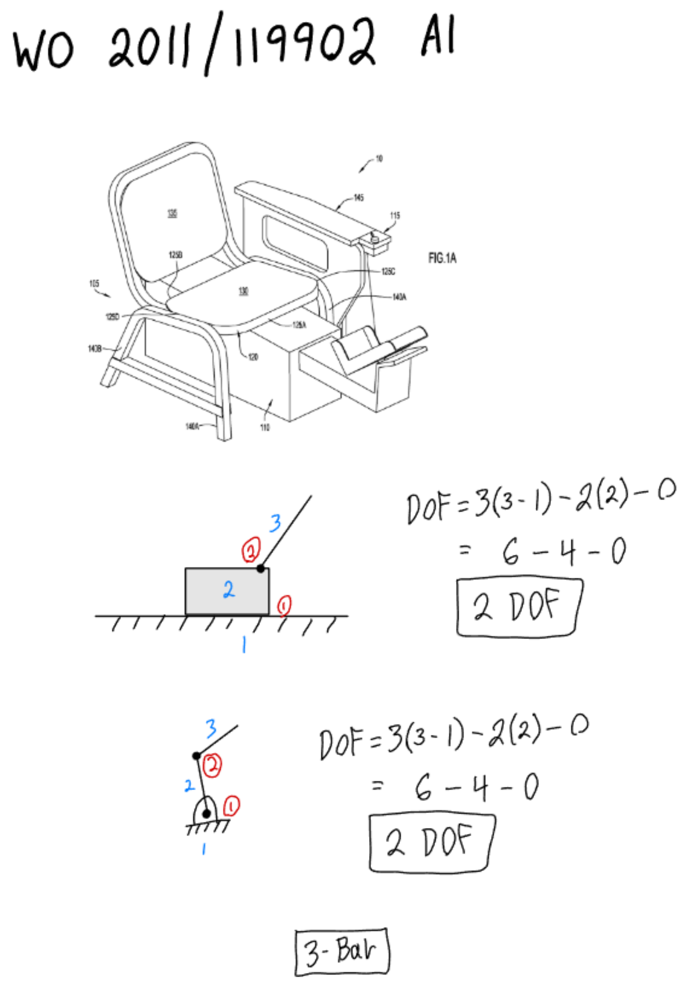

Figure 32: Kinematics diagram for WO2011119902A1 continuous passive motion device.

16.4 Degrees of Freedom

$$DOF = 3(n-1) - 2f_1 - f_2$$
$$DOF = 3(3-1) - 2(2) - 0$$
$$DOF = 2$$

The mechanism is a 3 bar linkage with 2 degrees of freedom.

16.5 Observations

This international patent presents a CPM arrangement in which a patient remains seated and a sliding member moves longitudinally to drive a pivoting foot pedal mechanism. The drive is implemented via a cable wrapped around a drum, driven by a reversible motor, with the cable pulling the slide back and forth over pulleys. The foot pedal is pivotally attached to the slide, enabling adjustment for different heel positions. A control switch interface allows the patient to set motion direction. The design shifts away from full-leg support systems to a more compact seated format, potentially increasing usability and convenience for home or clinical settings. However, the use of cable-driven actuation may introduce slack, friction, or backlash in the system, and the kinematics are limited by the fixed cable path and pulley geometry.

16.6 Opportunities for Improvement

To enhance this design, replacing or augmenting the cable drum drive with a stiffer actuation system would reduce compliance, backlash, and maintenance. Adjustable or interchangeable cable-guiding pulleys or routing paths could tailor motion profiles to individual patients, improving ergonomics. Lastly, a smoother motion profile (gradual acceleration/deceleration) could be implemented to reduce abrupt transitions and patient discomfort.

Appendix: Mechanism Summary Table

Table 1: Summary of patent mechanisms and kinematic properties

Page	Patent No.	Links	f_2	f_1	DOF	BKC Links	Chain/Structure	Task
5	US4509509A	7	0	8	2	7	Watt II + extra link	Motion
7	US4549534A	7	0	10	1	6	Watt II	Motion
8	US4566440A	14	0	19	1	12	Watt I	Motion
10	US4974830A	4	0	4	1	4	4-Bar	Motion
12	US5333604A	9	0	11	2	9	Watt II + 4-Bar	Motion
14	US6267735B1	6	0	7	1	6	Watt I	Motion
16	US6325770B1	5	0	6	0	5	Watt I	Motion
18	US5252102A	4	0	4	1	4	4-bar	Function
20	US4492222A	6	0	7	1	6	Watt I	Motion
22	US10272291B2	2	0	1	1	2	Slider	Path
24	US4603687A	8	0	10	1	8	Watt I + extra dyad	Motion
26	US5239987A	4	0	4	1	4	4-bar	Motion
29	US4546763A	6	1	6	1	6	Watt I	Motion
31	US4637379A	3	0	2	2	3	3-bar	Motion
33	US4665899A	5	0	5	2	5	4-bar like	Motion
35	WO2011119902A1	3	0	2	2	3	3-bar	Path