Slot Machine Peripheral Devices (continued)
Overview

• Items to be covered:
  • Reel Stepper Motors
    • Theory of Operation
    • Locations
  • Reel Assemblies
    • Major Components
  • Physical/Virtual Reel Strips
    • Pay Tables and PAR Sheets
    • Pseudo Random Number Generator
Reel Stepper Motors

• **Overview**
  • **A stepper motor is an device**
    • Which converts electrical signals (such as from a CPU) into discrete mechanical movements.
  • **The shaft or spindle of a stepper motor rotates in discrete step increments** when electrical command pulses are applied to it in the proper sequence.
    • **Direction of rotation**
      • Is directly related to the sequence of the applied pulses
    • **The speed of the motor shafts rotation**
      • Is directly related to the frequency of the input pulses
    • **The length of rotation**
      • Is directly related to the number of input pulses applied.
Reel Stepper Motors

• Overview
  • Advantages of using Stepper Motors
    • The rotation angle of the motor is proportional to the input pulse.
    • The motor has full torque at stand still (if the windings are energized)
    • Precise positioning and repeatability of movement since good stepper motors have an accuracy of 3 - 5% of a step and this error is non cumulative from one step to the next.
    • Excellent response to starting/ stopping/reversing.
    • Very reliable since there are no contact brushes in the motor. Therefore the life of the motor is simply dependant on the life of the bearing.
    • The motors response to digital input pulses provides open loop control, making the motor simpler and less costly to control.
Reel Stepper Motors

• Overview
  • Advantages of using Stepper Motors
    • It is possible to achieve very low speed synchronous rotation with a load that is directly coupled to the shaft.
    • A wide range of rotational speeds can be realized as the speed is proportional to the frequency of the input pulses.
  • Disadvantages of using Stepper Motors
    • Resonance movements can occur if not properly controlled.
    • Not easy to operate at extremely high speeds.

• Types of Stepper Motors
  • *Variable reluctance (VR)*
    • This type of stepper motor has been around for a long time.
Reel Stepper Motors

• Types of Stepper Motors
  • Variable reluctance (VR)
    • It is probably the easiest to understand from a structural point of view.
      • Figure 1 shows a cross section of a typical V.R. stepper motor.
        • This type of motor consists of a soft iron multi-toothed rotor and a wound stator.
      • When the stator windings are energized with DC current the poles become magnetized.
    • Rotation occurs when the rotor teeth are attracted to the energized stator poles.
Reel Stepper Motors

• **Types of Stepper Motors**
  
  • *Permanent Magnet (PM)*
    • Often referred to as a "tin can" or "canstock" motor
    • Is a low cost and low resolution type motor
      • Typical step angles of 7.5 degrees to 15 degrees. (48 - 24 steps/revolution) PM motors
    • Has permanent magnets added to the motor structure.
      • The rotor no longer has teeth as with the VR motor.
      • Instead the rotor is magnetized with alternating north and south poles situated in a straight line parallel to the rotor shaft.
Reel Stepper Motors

• Types of Stepper Motors
  • *Permanent Magnet (PM)*
    • Motor structure (continued)
      • These magnetized rotor poles provide an increased magnetic flux intensity
        • Thus the PM motor has improved torque characteristics when compared with the VR type.
  • Hybrid (HR)
    • More expensive than the PM stepper motor but provides better performance with respect to step resolution, torque and speed
      • Typical step angles for the HR stepper motor range from 3.60 to 0.90 (100-400 steps per revolution).
      • Combines the best features of both the PM and VR type stepper motors.
Reel Stepper Motors

• Types of Stepper Motors
  • Hybrid (HR)
    • Price/Performance (continued)
      • The rotor is multi-toothed like the VR motor
        • Contains an axially magnetized concentric magnet around its shaft.
        • The teeth on the rotor provide an even better path which helps guide the magnetic flux to preferred locations in the air gap.
        • This further increases the detent, holding and dynamic torque characteristics of the motor when compared with both the VR and PM types.
  • Most commonly used types
    • Permanent magnet
      • Normally several times less expensive
    • Hybrid types
Reel Stepper Motors

• **Types of Stepper Motors**
  • **Size and Power Considerations**
    • Also classified by their frame sizes
      • Correspond to the diameter of the body of the motor.
        • For instance a size 11 stepper motor has a body diameter of approximately 1.1 inches.
        • Likewise a size 23 stepper motor has a body diameter of 2.3 inches (58 mm), etc.
      • The body length may however, vary from motor to motor within the same frame size classification.
        • As a general rule the available torque output from a motor of a particular frame size will increase with increased body length.
    • Also classified by their power usage
      • Power levels for IC-driven stepper motors typically range from below a watt for very small motors up to 10 -20 watts for larger motors.
Reel Stepper Motors

• Types of Stepper Motors
  • Size and Power Considerations
    • Also classified by their power usage
      • The maximum power dissipation level or thermal limits of the motor are seldom clearly stated in the motor manufacturers data.
      • The motor is designed to be and should be used at its maximum power dissipation, to be efficient from a size/output power/cost point of view.

• When to use a Stepper Motor
  • Whenever controlled movement is required.
    • In applications where you need to control rotation angle, speed, position and synchronism.
  • Used in many different applications.
    • Some of these include printers, plotters, high end office equipment,
      • hard disk drives, medical equipment, fax machines, slot machines, automotive and many more.
Reel Stepper Motors

• Mechanical Parameters, Load, Friction, Inertia
  • The performance highly dependent on the load
    • The load is defined as what the motor drives.
    • It is typically frictional, inertial or a combination of the two.
  • Frictional Load
    • Resistance to motion due to the unevenness of rubbing surfaces
      • Friction is constant with velocity.
    • Minimum torque level is required to overcome this friction
      • At least equal to the friction
      • Increasing load lowers the top speed and increases the positional error.
      • The converse is true if the frictional load is lowered.
  • Inertia
    • Resistance to changes in speed
Reel Stepper Motors

• Mechanical Parameters, Load, Friction, Inertia
  • Inertia
    • The greater the mass of the object the greater the inertia
  • On Slot Reels
    • A high inertial load requires a high inertial starting torque and the same would apply for braking.
    • Increasing an inertial load will
      • Increase speed stability,
      • Increase the amount of time it takes to reach a desired speed
    • Converse is again true if the inertia is decreased.
Reel Assemblies

• Major Components
  • Reel Strip
  • Reel
  • Reel Optics
  • Stepper motors

• Reel Strip
  • Tied directly to the game’s program which is stored on EEPROM or Flash memory
  • Listed on the PAR sheet as the key identifier
  • Symbol placement usually not the same for on each strip for a machine
Reel Assemblies

• Reel Strip
  • Keyed at one end
    • Aids in placement on reels
    • Must start at only one location
    • If not placed correctly false wins will display for users
      • Casino nightmare
  • Match the game theme

• Reel
  • Cage
    • Driven by Stepper Motor
Reel Assemblies

• Reel
  • Cage
    • Has a Slotted disk
      • Slots used with optics to:
        • Help the processor determine reel location
    • Has a keyed surface for holding the strips
  • In Class Exercise
    • Replace/Reinstall Strip
      • Two Thumb Method
      • Cupped strip method
Reel Assemblies

• Reel
  • Win Lights
    • Newer games usually have a bank of lights to highlight wins
    • Don’t rotate with the cage but illuminate symbols on the reel when there is a win
  • Base
    • New machines the reels slide into place and make electrical and data connects at the same time
Reel Assemblies

• Reel
  • Base
    • On older machines the electrical and data connects
    • Attached to bottom after placement

• Reel Optics
  • Used with the slotted disk on the cage
    • Helps processor to determine reel position
    • LED on one side of disk
    • Light sensor on the other side
Physical/Virtual Reel Strips

• Pay Tables and PAR Sheets
  • Overview
    • On May 15, 1984 patent number 4,448,419 was issued to Inge S. Telnaes which is the basis of all current slot machines.
      • "A gaming machine of the type utilizing rotating reels which carry on the periphery a plurality of indicia, a brake to stop the reels at a selected position and a random number generator for selecting the reel stopping position. Numbers are assigned to the reel stopping positions and entered into the random number generator with each number being entered one or more times to control the payout odds of each particular stopping position being selected thereby enabling any odds to be set without changing the physical characteristics of the machine."
    • The use of Stepping motors eliminated the need for a brake
Physical/Virtual Reel Strips

• Pay Tables and PAR Sheets
  • Overview
    • Patent number 4,448,419 (continued)
      • "...A random number generator is provided with electronic circuitry which computes the random stop position at which the reel should be stopped by the physical brake.
      • This is done with an electronically random number selected from a group of numbers which exceeds the number of physical reel positions
        • Such that one physical reel position is represented by one or several positions on the virtual or electronically generated reel
        • The virtual or electronically generated reel which is in affect, randomly stopped by the random number generator.
      • In this invention the physical reels are only used as a display of the random number generated result and are not the game itself
Physical/Virtual Reel Strips

• Pay Tables and PAR Sheets

• Overview
  • *In this manner, a standard slot machine or gaming apparatus can*
    • *Function at payout odds, independent of the limits set by the number of physical reels and their physical stop positions,*
    • *By simply changing the random number generator.*

SIXTY FOUR VIRTUAL REEL POSITIONS MAPPED TO TWENTY TWO REEL POSITIONS
Physical/Virtual Reel Strips

• Pay Tables and PAR Sheets
  • **Overview**
    • *In this manner, a standard slot machine or gaming apparatus can*
      • *Function at payout odds, independent of the limits set by the number of physical reels and their physical stop positions,*
      • *By simply changing the random number generator.*
  • **Simple Slot Math**
    • **Definitions**
      • **Stops** = Reel positions, positions at which the reel can stop
      • **Machine Cycle** =
        • Total number of possible combinations, calculated by multiplying the total number of stops of all the reel positions
        • Reel 1 positions x Reel 2 positions x Reel 3 positions, and so on
Physical/Virtual Reel Strips

• Pay Tables and PAR Sheets
  • Simple Slot Math
  • Definitions
    • Hits/Cycle = Number of times a certain jackpot combination theoretically lines up during one machine cycle
    • Jackpot Odds = Theoretical odds of hitting a certain jackpot on any given handle pulls
    • Hit Frequency = Theoretical percentage of plays involving a pay. The number of combinations involving a pay ÷ cycle = hit frequency
    • Win Frequency = Theoretical number of plays between pays. Cycle ÷ number of combinations involving a pay = win frequency
  • Number of Stops/Combination/Machine Cycle
    • Example 1 -- 32-stop, 3-reel game:
      • 32 x 32 x 32 = 32,768 combinations
    • Example 2 - 64-stop, 4-reel game:
      • 64 x 64 x 64 x 64 = 16,777,216 combinations
Physical/Virtual Reel Strips

• Pay Tables and PAR Sheets
  • Simple Slot Math
    • Hits Per Cycle and Jackpot Odds
      • Example 1 – With 3 – 32 stop reels. What are the odds of hitting the top jackpot of three 7s when the number of 7s per reel are: Reel 1 = 2; Reel 2 = 2, and Reel 3 = 1?
        • Step 1: Determine the total possible jackpot combinations.
          - The # of jackpot combinations = Reel 1 # of winning symbols x Reel 2 # of winning symbols x Reel 3 # of winning symbols.
          - In this case, 2 x 2 x 1 = 4 hits/cycle.
        • Step 2: Jackpot odds = (machine cycle ÷ hits/cycle).
          - In this case, 32,768 ÷ 4 = 8,192:1
          - Which means the jackpot should hit every 8,192 pulls
      • Example 2 - 64-stop, 4-reel slot game:
        • What are the odds of hitting the top jackpot of four Jokers when the number of Jokers per reel are:
Physical/Virtual Reel Strips

• Pay Tables and PAR Sheets
  • Simple Slot Math
    • Hits Per Cycle and Jackpot Odds
      • Example 2 - 64-stop, 4-reel slot game:
        • Reel 1 = 2, Reel 2 = 2, Reel 3 = 2, and Reel 4 = 2
        • Step 1: Compute the possible jackpot combinations.
          - 2 x 2 x 2 x 2 = 16 jackpot combinations, or hits/cycle
        • Step 2: Compute the jackpot odds. 16,777,216 ÷ 16 = 1,048,576:1
          (which means the jackpot should hit every 1,048,576 pulls).
    • Hit Frequency and Win Frequency
      • Example 1 - 3-reel, 32-stop game that has 3,277 pay combinations:
        • What is the hit frequency? 3,277 / 32,768 x 100 = 10% hit frequency
        • What is the win frequency? 32,768 / 3,277 = 10 games between pays
      • Example 2 - 64-stop, 4-reel game has a 15% hit frequency:
        • How many pay combinations are there? 16,777,216 x 15/100
          = 2,516,582 pay combinations
Physical/Virtual Reel Strips

• Pay Tables and PAR Sheets
  • Simple Slot Math
    • *Hit Frequency and Win Frequency*
      • Example 2 - 64-stop, 4-reel game has a 15% hit frequency:
        • *What is the win frequency?* Win frequency = 1 / hit frequency = 1 / 15% = 6.67 games between pays
  • Watch the PAR video clip

• Pseudo Random Number Generator
  • Overview
    • A random number generator is an electronic device that is used to select outcomes in slot machines.
    • They are programmed to reflect the desired payout percentage determined by the Casino
      • Which cannot be set below the legal minimum.
Physical/Virtual Reel Strips

• Pseudo Random Number Generator
  • A random number generator is an electronic device that is used to select outcomes in slot machines.
  • Legal Minimums are determined by the Gambling commission in the State to which the machine is delivered.
  • Payout settings can be as high as the Casino wishes them to be but cannot go below the minimum.
  • That is why you see various slot payouts at different casinos,
    • Some will advertise 95.9% payback while another will proclaim a 97.5% payback.
      • What this means is that the casino will hold the difference between the stated payback and 100% as their profit margin on all monies played through a particular machine.
Physical/Virtual Reel Strips

- Pseudo Random Number Generator
  - *The RNGs are in constant motion.*
    - There seems to be differences of opinion as to when, in the process of playing a slot machine, the outcome is actually selected.
    - This is highly classified information which the Casinos and Manufacturer guard closely
    - The best guesses suggest that selections of outcomes are made by the RNG when the last credit is played or the handle is pulled (or spin-button is activated).
      - This would suggest that if you play one credit and engage the slot machine the outcome has been determined.
      - However if you play a second credit, the outcome will be different from the first credit and so on.
    - Another guess is that the first credit is played, selects the outcome
      - Subsequent credits played have no further effect on the outcome.
Physical/Virtual Reel Strips

• Pseudo Random Number Generator
  • Introduction to Pseudo random Numbers
    • All random number generators are based upon specific mathematical algorithms, which are *repeatable* and *sequential*.
      • Thus, the numbers are just *Pseudo random*.
  • Definitions
    • Truly random - is defined as exhibiting "true" randomness,
      • Such as the time between "tics" from a Geiger counter exposed to a radioactive element.
    • Pseudo random - is defined as having the appearance of randomness, but nevertheless exhibiting a specific, repeatable pattern.
    • Quasi-random - is defined as filling the solution space sequentially
      • These sequences are not at all random - they are just comprehensive at a preset level of granularity).
Physical/Virtual Reel Strips

• Pseudo Random Number Generator

• Definitions
  • Quasi-random - is defined as filling the solution space sequentially
    • For example, consider the integer space [0,100]. One quasi-random sequence which fills that space is 0, 1, 2,...,99, 100. Another is 100, 99, 98,...,2, 1, 0. Yet a third is 23, 24, 25,..., 99, 100, 0, 1,..., 21, 22. Pseudo random sequences which would fill the space are

• Random Number Cycle
  • Pseudo random sequences have a cyclical structure
    • They repeat
  • The random number sequence or cycle can have either integers or real number
    • We confine ourselves to integers.
Physical/Virtual Reel Strips

• Pseudo Random Number Generator
  • Random Number Cycle
    • Characteristics
      • The sequence has a finite number of integers,
      • The sequence gets traversed in a particular order
      • The sequence repeats if the period of the generator is exceeded (i.e., the cycle can be traversed more than once)
  • Some types of Pseudo Random Number Generators
    • Linear Congruential
    • Lagged Fibonacci
    • Shift Register
  • Linear Congruential
    • Uses the following equation

\[ X_{n+1} = aX_n + c(MODm) \]
Physical/Virtual Reel Strips

- Pseudo Random Number Generator
  - Linear Congruential
    - Key
      - $X_{n+1}, X_n$ are random integers
      - $X_0$ is the seed value used to start the sequence
      - “a” is the multiplying consent
      - “c” is the adding consent
      - “m” is the modulus
    - Standard representation
      - LCG($a$, $c$, $m$, $X_0$)
    - Example 1 – LCG(5, 1, 16, 1)
      - $X_{n+1} = 5(1) + 1 \pmod{16} = 6$
        - $\Rightarrow 6/16 = 0$ with a remainder of 6
      - $X_{n+1} = 5(6) + 1 \pmod{16} = 15$
        - $\Rightarrow 31/16 = 1$ with a remainder of 15

$$X_{n+1} = aX_n + c(MODm)$$
Physical/Virtual Reel Strips

- Pseudo Random Number Generator

  - Linear Congruential
    - Example 2
      - LCG (5, 0, 16, 1)
        - What is the sequence and the period?
    - Example 2
      - LCG (5, 0, 37, 1)
        - What is the sequence and the period?

\[ X_{n+1} = aX_n + c \text{ (MOD} m) \]