Triple Cam Stepless Variable Transmission

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Abstract - A continuously variable transmission (CVT) is a type of transmission that allows an infinitely variable ratio change within a finite range, allowing the engine to continuously operate in an efficient or high performance range. A brief history of CVTs is presented, including the families under which they can be categorized. A new family of CVTs, with the classification of positive engagement, is presented. Three different published embodiments of CVTs of the positive engagement type are presented describing a meshing problem that exists apparently regardless of the embodiment in this family. The problem is called the non-integer tooth problem and its occurrences are detailed in each of the three embodiments. Specific solutions to the problem, as embodied in each case, are presented. The proposed embodiment of a new, positive engagement, continuously variable transmission is described in detail with the derived general kinematic equations of its motion. The kinematic equations for two variant embodiments are also derived. The results of the meshing analysis for this new embodiment are given and the non-integer tooth problem is exposed in three different operating conditions of the CVT. Characteristics of a solution to the non-integer tooth problem are then described, which are applicable to positive engagement family in general.

Keywords* - *CVT – Continuously Variable Transmission, IVT – Infinitely Variable Transmission.

I. INTRODUCTION

The primary function of a transmission is to transmit mechanical power from a power source to some form of useful output device. Since the invention of the internal combustion engine, it has been the goal of transmission designers to develop more efficient methods of coupling the output of an engine to a load while allowing the engine to operate in its most efficient or highest power range. Conventional transmissions allow for the selection of discrete gear ratios, thus limiting the engine to providing maximum power or efficiency for limited ranges of output speed. Because the engine is forced to modulate its speed to provide continuously variable output from the transmission to the load, it operates much of the time in low power and low efficiency regimes. A continuously variable transmission (CVT) is a type of transmission, however, that allows an infinitely variable ratio change within a finite range, thereby allowing the engine to continuously operate in its most efficient or highest performance range, while the transmission provides a continuously variable output to the load. The development of modern CVTs has generally focused on friction driven devices, such as those commonly used in off-road recreational vehicles, and recently in some automobiles. While these devices allow for the selection of a continuous range of transmission ratios, they are inherently inefficient. The reliance on friction to transmit power from the power source to the load is a source of power loss because some slipping is possible. This slipping is also a major contributor to wear, which occurs in these devices. To overcome the limitations inherent in the current CVT embodiments employing friction, a conceptual, continuously variable, positive engagement embodiment has been proposed for investigation at Brigham Young University. This concept proposes utilizing constantly engaged gears which transmit power without relying on friction. Because the proposed embodiment is new, no engineering analysis has yet been performed to determine its kinematic and meshing characteristics, an understanding of which are necessary to validate the proposed concept as a viable embodiment. This research will investigate both the kinematic and meshing characteristics of this and related concepts. The objective of this research is also to analyse the family of positive engagement CVTs. Although the CVT embodiment that has been proposed for investigation is new, other embodiments belonging to this family have been developed and published. The embodiments in this family do not rely on friction based power transmission. All embodiments in this family, however, have been based on overcoming a distinct problem which manifests itself

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seemingly regardless of the embodiment and will hereafter be referred to as the non-integer tooth problem. This research describes the nature of the non-integer tooth problem and details the occurrence of the problem in the proposed concept, as well as three published embodiments, and details solutions to the non-integer tooth problem as embodied in the three published embodiments. The presentation of some published solutions to the non-integer tooth problem clarifies the nature of the non-integer tooth problem, as well as aids in the development of characteristics of a general solution to the non-integer tooth problem applying to all members of the positive engagement CVT family. Because the intention of this research is to provide greater understanding of the positive engagement CVT family, this research will not focus on the actual design of positive engagement embodiment. The aim of this research is provide a foundation for future research involving the engineering design of functioning, efficient and robust positive engagement CVT embodiments.

II. LITERATURE SURVEY

Dr. N. Arunkumar, (2014) Presented paper on infinitely Variable Transmission Using Four Bar Mechanism**.** This paper present Most of the continuously variable transmission systems in automobiles now-a-days are non-positive drives. This means that they cannot be used in heavy vehicles that require very high torque to be transmitted. This new type of infinitely variable transmission is aimed at transmitting high torques by making it a positive drive, thus making continuously variable transmission systems to be suitable for heavy vehicles. Infinitely variable transmission system and continuously variable transmission system are both the same except that there is an extra zero gear ratio in infinitely variable transmission system. This newly developed transmission system is basically a four bar mechanism with variable crank radius which makes it possible to have continuously variable mechanical advantage. The output lever which oscillates in the four bar mechanism is connected to a ratchet mechanism which turns the output shaft intermittently, two four bar mechanisms with a phase difference of 180 degrees is used to avoid the intermittent rotation of the output shaft. A flywheel is used in the output shaft to reduce the fluctuations in both speed and torque.

C. Gregory F. Hickman (2013) Presented paper on Kinematic Modeling and Analysis of a Cam Based CVT for a Capstone Design Project Experience**.** This paper presents a Capstone Design Project at Oakland University, a CAD model of a cam based CVT (Continuously Variable Transmission). The Capstone Design Project at Oakland University covers a broad range of mechanical engineering core disciplines of kinematics, dynamics, material properties and mechanics, machine design, and serves as an integration course before mechanical engineering students' graduate. It takes students through the entire taxonomy of the design process: from searching for ideas, proposal, survey, knowledge, comprehension, application, to analysis, synthesis, and finally evaluation and modification. This project was performed by a group of mechanical engineering senior students, to demonstrate their engineering training and capabilities to search for ideas, to formulate a proposal and modify it to get the approval from the department curriculum committee, to conduct literature survey, to understand the descriptions of a new mechanism, to design and construct a virtual prototype in the computer environment, and finally to propose modifications to improve the original design. This project is to investigate a novel cam based CVT which was proposed in US patent # 4,603,240, which has a cam input to drive an angle dependent, clutch actuated output shaft.

D. Amjad M. Abood (2009), Presented paper on A Novel Cam-Based Infinitely Variable Transmission**.** This paper presents infinitely variable transmission system, is the system which allows for continuous variation of transmission ratio including zero transmission ratio. In this paper, the geometric design and kinematics analysis for a novel cam based infinitely variable transmission system are presented. The proposed system has a number of identical units, each unit contains three dimensional cam follower, grooved wheel, and one way clutch (ratchet). Through each unit the rotational motion is converted to an oscillatory linear motion of variable amplitude and then rectified to rotational motion again. The. On the other hand, during transmission ratio variation there is a little fluctuation in the values of the output angular velocity and acceleration. This fluctuation is decreased when the number of units is increased. Also it was concluded that the maximum transmission ratio of the system depends on the geometric design factors.

III. PROPOSED SYSTEM

There are many machines and mechanical units that under varying circumstances make it desirable to be able to drive at an barely perceptible speed , an inter mediate speed or a high speed. Thus a infinitely variable or stepless speed variation in which it is possible to get any desirable speed. Some mechanicals hydraulic and electrical devices serve as such stepless drives .However the torque VS speed characteristics of these drives do not match that of stepless drives at increased driving torque at low speeds.

In many drives, it is desirable to be able to shift from one speed to another without stopping the machine and also be able to obtain any speed between the max and min. A design which meets these requirements is the triple cam stepless variable transmission.

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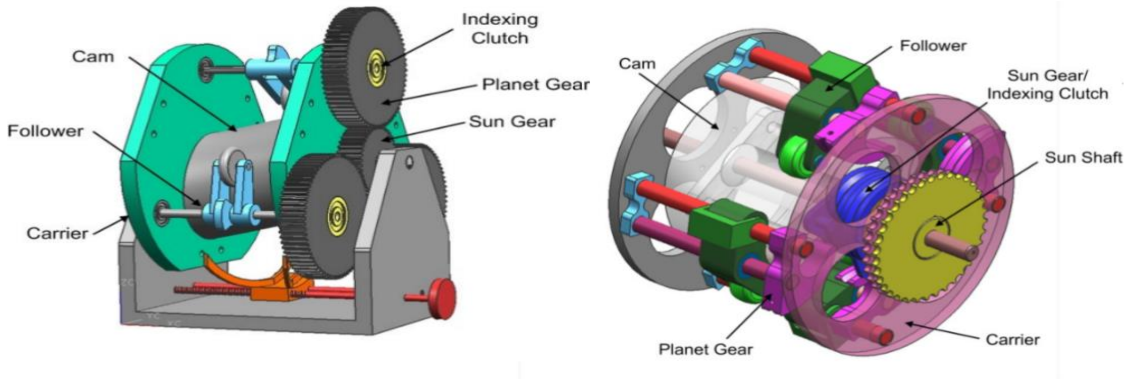

Fig. 1 Major components of a simplified representation of cam-based IVT on left, and the complete prototype on right.

In its simplest form, this transmission contains six unique components. Each component is described here briefly and illustrated in the following figures. While their function may be allowed to here, it is more completely described in Section 2-1. The heart of this transmission is a centrally located three dimensional cammoid. It is sometimes referred to as simply "cam" but this is somewhat undescriptive as a cammoid has a continuously varying profile along its length. The cammoid is most often fixed to ground, but can also serve as the input or output. Around the cammoid are a number of followers. Each follower interacts with the cammoid through a spherical or ellipsoidal roller mounted on said follower. The followers are held to the cam surface when not under load by a return spring. The followers are rotatably mounted to one or two carrier plates, the third major unique component of the transmission. The carriers are used to support the followers as well as transmit the input and output torques in some inversions. This is analogous to a carrier's function in a planetary gear set.

When designed to rotate, the carriers do so about the central axis of the cam. On each follower, is fixed a planet gear or pulley which meshes with a sun gear. The sixth and final unique component of the Cam-based IVT is a one way clutch located inside each of the planet gears or the sun gears. These clutches are responsible for rectifying the oscillations generated by the cam and followers and can be connected on the race opposite the sun gear to either the input, output, or ground depending on the inversion specified. The shaft connected to this inner race of the sun gears is simply called the sun gear shaft and its sole purpose is to transmit torques from an external source to both of the sun gears (however usually not at the same time). If however the sprag clutches are located in the planet gears, the sun shaft is directly connected to only one sun gear. These components are labelled on both a simplified representation and a prototype CAD model in **Figure 1.**

Attention is now given to the operation of the Cam-based IVT, specifically, how the major components detailed above interact to generate a smooth output motion at infinitely many transmission ratios. There are six different inversions of the Cam-based IVT, and while the majority of this work is focused on one particular inversion, the operation of the transmission is better first illustrated with a dynamically simpler one. Therefore the configuration first presented here uses the cam as the input and the sun gear shaft as the output.

Figure 1. Major components of a simplified representation of the Cam-based IVT on left, and the complete prototype on right. The version on left has its sprag clutches in the planet gears while the version on right has them in the sun gears. Consider now the simplest inversion the Cam-based IVT which can be thought of as simply a cam and follower system with an attached gear train. Therefore the cam will serve as the input and the sun gear shaft as the output while the carriers remain fixed to ground. In such a configuration, a rotational input to the cam causes the followers to simply oscillate up and down as they are held to the cam with the return springs. In this case the followers do not rotate around the cam because the carrier is fixed. Due to the shape of the cam and the position of the followers around the cam ,the followers oscillate out of phase of one another, that is, one follower will rotate clockwise, while the other rotates predominately counter clockwise. The out of phase oscillations of the followers drives the planet gears and their respective sun gears back and forth. It follows then that one direction of the oscillations of the sun gears will be transmitted to the sun gear shaft through the one way clutches. Because one sun gear will always be moving faster in the locking direction of the clutches, one sun will transmit torque to the sun gear shaft. With a carefully designed cam profile, the velocity of the sun gears can be shaped to produce a smooth and continuous output of the sun gear shaft with no velocity ripples. Such a velocity profile would look something like that when overlaid with the velocity profile of the other out of phase followers, it would appear as in **Figure 2.**

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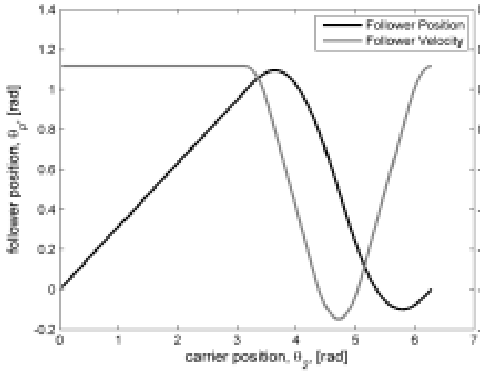

Figure 2-2. Displacement and Velocity profile.

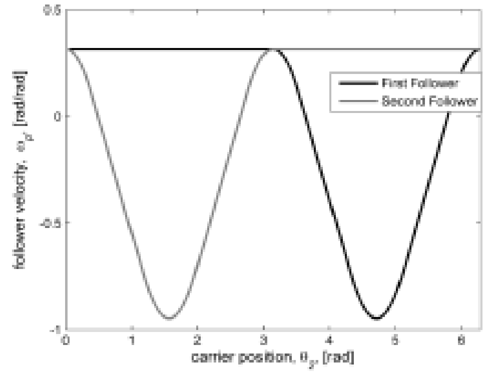

Figure 2-3. Three velocity profiles overlaid out of phase.

Fig 2 velocity and displacement profile

The inversion studied for the majority of this work utilizes the sun gear shaft as the input, and the carriers as the output. As will be elaborated on later, this particular inversion was chosen because it provides higher gear ratios as well as a larger gear ratio range for a given cam eccentricity. It has been experienced that this inversion is more difficult to visualize then others, but much clarity can be gained by picturing something similar and much more familiar, a planetary gear set. To fully describe its motion, first a circular cam is considered. This will decouple the motion of the carrier and the followers around the cam, from the oscillations of the followers. Once these dynamics are understood, it is only a small step to superimpose follower oscillations and their effects on the carrier motion to understand the full system. To begin, first consider a perfectly circular cam as in **Figure 2** A clockwise rotation applied to the sun gear is transmitted by all one way clutches as a counter clockwise rotation on the planet gears. Such a motion will force the follower down onto the cam and because they cannot rotate in this direction (due to the cam reaction force) the carrier will then rotate around the cam. The carrier rotates with a 1:1 ratio to the sun gear.

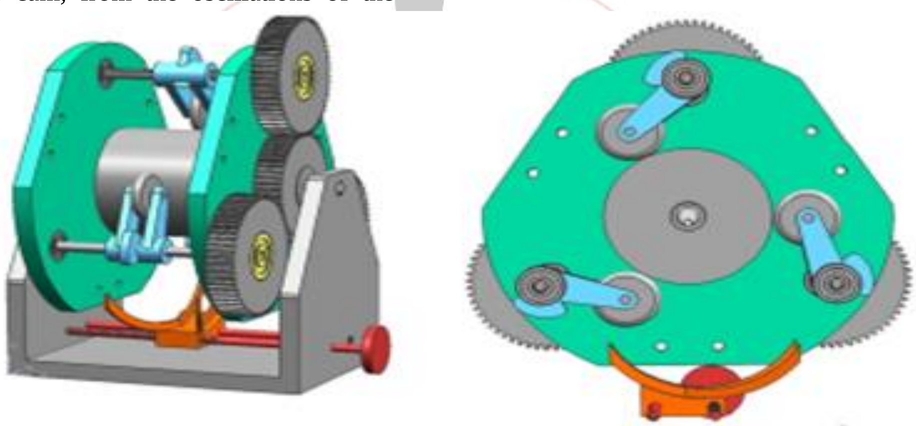

Fig. 3 Schematic of IVT with round cam.

Now consider a non-circular cam. The operation is nearly the same as above; a clockwise rotation on the sun gear shaft forces one of the followers down onto the cam. Since the follower cannot rotate in this direction, the sun gear rotation causes the carrier to rotate about the cam just as above. Except this time, as the carrier rotates around the cam, the follower will rotate in relation to the carrier as it follows the lobes of the cam. For example, when the follower moves up onto a cam lobe, it and the attached planet gear will rotate in a clockwise direction in relation to the carrier. Here the operation is similar to a planetary gear set, where the rotation of the carrier depends upon both the sun gear and the planet gear rotations. Specifically, the relative clockwise rotation of the planet gears forces them to rotate (or walk) around the sun gear in a clockwise direction. As the planet gears orbit the sun gear they move the carrier along with them, advancing its position with respect to the sun gear. Because the carrier is the output, a non circular cam will create transmission ratios greater than unity. The reader will note that only one follower was considered in the above analysis. This follower, the one under load, is called the active follower. This is because while the active follower is moving up a cam lobe, the second or third followers, called the inactive followers, should be moving down a lobe and will be rotating in a counterclockwise direction with respect to the carrier as a result. A counterclockwise rotation of the attached planet gear will rotate the meshing sun gear further clockwise, in a direction that disengages the one way clutch. (Because the sun gear shaft rotates clockwise, they are installed such that they lock up with a counter clockwise application of torque on the sun gear race.) Therefore as one sun gear transmits torque to the carrier and cam, the second is freewheeling faster in the same direction, but one gear is always.

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The word 'transmission' means the whole of the mechanism that transmit both motion and power from the source of energy to the application where it is to be used. However the transmission is also being used very commonly in literature for a mechanism which provides us with suitable variation of engine torque at the application; either in the amplified or reduced form.

IV. Propose System VS Existing System

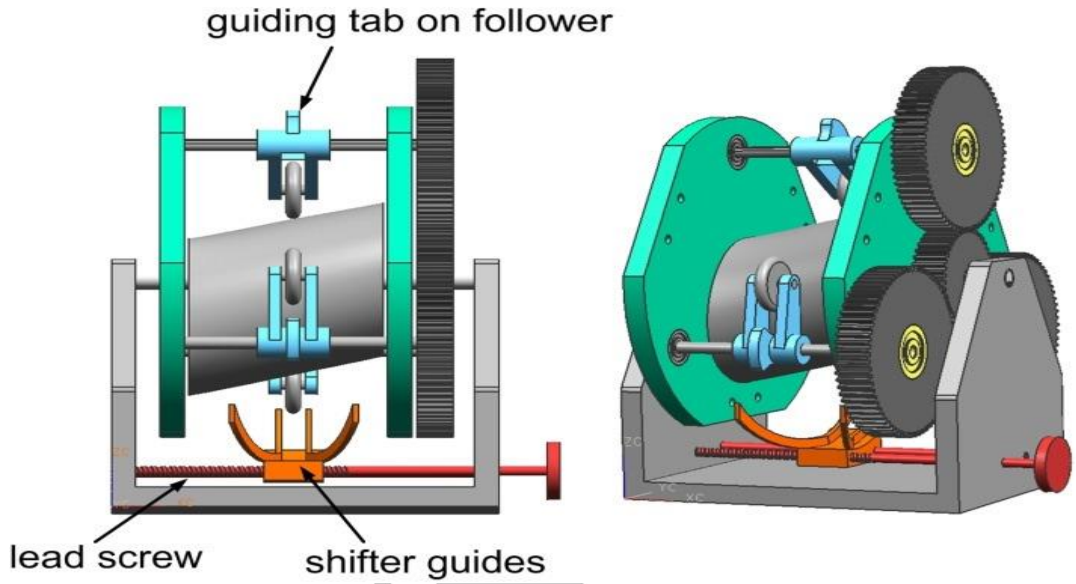

Figure 4 The front and isometric view of a concept transmission showing the shifting mechanism.

The shifting capabilities of the Cam-based IVT are particularly unique, especially when compared to those of traction drives. Specifically, many traction drives require large and powerful shifting mechanism to reposition components in relation to one another as they transmit power. For traction drives this can be particularly problematic because of the large normal forces necessary to generate traction. Belt and torroidal drives are noteworthy examples. However, as with all ratcheting drives, at least one of the drive components (the follower in the case of the Cam-based IVT) is unloaded for some time. Repositioning these components when unloaded eases the task of shifting. This is a characteristic unique to the Cam-based IVT even amongst other ratcheting drives. As mentioned before, the cam is made up of an infinite number of profiles along its length; therefore, the cam's cross section continuously changes along its length, as can be seen in Figure. It changes from a circular shape on one end to an oblong or peanut shape on the other Shifting the transmission between gears is accomplished by positioning the followers on different profiles along the cams length. This affects the magnitude of the follower's oscillations and therefore the output of the transmission in which the followers' position along the cam determines the pressure angle, α, which thereby determines the torque applied to the carrier and therefore transmission ratio. Isometric and front view of a 3-D cammoid model installed in the first prototype. While shifting, to move either the cam or the followers under load, would require the shifter to overcome the high static friction between the roller and the cam. In addition, as a follower moves across the cam, it may also rotate as it moves onto a larger lobe. If this rotation is in the same direction required to activate the indexing clutches, the followers will then be transmitting torque to the output, and therefore part of the shifting load will be required to drive the output. A unique advantage of a ratcheting drive though, is that the followers are unloaded on a portion of the cam as they rotate in a direction that disengages the one way clutches. This allows them to be repositioned with less force, and therefore, the shifting mechanism must only overcome the friction between the roller and the cam produced by the return spring. As the follower then enters the active profile of the cam, it will produce a different transmission ratio. One such concept for achieving this task can be seen in **Figure 4** In this design, each follower is built with a guiding tab, and as the carrier rotates the followers through the shifter guides, those guides will drive the follower across the cam to the desired profile. A lead screw is used to reposition the shifter guides to select different profiles. Although this design was never implemented in a prototype, it demonstrates the necessary functionality required of a shifter. A complete description of the shifting mechanism actually implemented on the prototypes is presented in the mechanical design portion of this work.

The Cam-based IVT is a unique transmission with many capabilities beyond that of other current ratcheting drives and IVT technologies such as the torroidal and belt driven types. Much like the torroidal drives, in which most if not all of the driving torque passes through a small contact region, the entire reaction force to the driving torque of the Cam-based IVT is transmitted through the contact area between the rollers and cam. Therefore, this small region exhibits a very high Hertzian

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contact stress which is proportional to the input torque. For a given transmission size, it was found that this contact stress is the limiting factor of the torque capacity of the transmission. While other highly stressed components can be resized to accommodate high loads, such as the sprag clutches, input shaft, and planetary gear system, the cam and roller system has a much greater effect on the overall transmission size than the other components. So for a given input torque, the overall size of the transmission was determined such that this contact stress was within the limits of both the cam and roller material. In the previous chapter, two optimization algorithms were employed to search a parameter space to minimize this contact stress. The results of these algorithms significantly reduced the contact stress to within acceptable levels thereby increasing the torque capacity of the transmission near to the desired capacity of 120[N-m]. This chapter addresses two major mechanical design improvements that were implemented on the Cam-based IVT to further reduce the contact stress through both the reduction of the contact force on the roller, and minimizing the stress resulting from this force. To reduce the contact force, increasing the number of followers, number of rollers, and/or changing the transmission parameters were studied. Aside from minimizing the contact force, changing the diameters of the contacting bodies, reducing the modulus of elasticity of the materials involved, or changing the geometry of the contact region were all suitable means of minimizing the stress for a given contact force. The end approach was two pronged, to at least double the number of rollers under load at any time, and also to modify the overall topology of the mechanism to incorporate an inverted and external cam surface which surrounded the rest of the mechanism. Utilizing a unique cable differential, which splits the input torque evenly between two followers, allowed for two active followers and therefore loaded rollers. Inverting the cam provided a larger radius of curvature and a more complimentary surface for the roller to follow. Both methods and their characteristics are presented here.

V. CONCLUSION

The analysis of the positive engagement CVT family reveals that all published embodiments belonging to this family must overcome a problem called the non-integer tooth problem. This research has described this problem as it exists in three published embodiments. This has been done to show several ways in which this problem can be manifest. This research has examined both the kinematic and meshing characteristics of the proposed embodiment, as well as two variant embodiments. From the derivation of the kinematic equations governing the motion of the proposed new transmission in its various embodiments, it can be concluded that each of the embodiments would function kinematically, allowing the selection of infinitely variable gear ratios over a finite range. The meshing analysis of the proposed embodiment, as well as the two variants, however, has shown that a meshing problem exists between the driving and driven portions of the transmission. This problem has been identified as the non-integer tooth problem.

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