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Design and analysis of indexing cam mechanism with parallel axes

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ABSTRACT

The indexing cam mechanism is one of the most crucial mechanisms in automated machinery. This study proposes a simple yet comprehensive method for the design and analysis of an indexing cam mechanism with parallel axes. In the proposed approach, an analytical description of the driving cam profile is obtained using coordinate transformation and conjugate surface theory. Formulae are then derived for the pressure angle of the indexing cam mechanism and the principal curvatures of the driving cam. Finally, the kinematic characteristics of the indexing cam mechanism are analyzed. The validity of the proposed design methodology is verified by machining an indexing cam on a 3-axis CNC machine. The results confirm that the proposed methodology enables the design and manufacturing tasks to be successfully integrated, thereby making possible a flexible, automatic, cost efficient and controllable production process.

1. Introduction

Indexing cam mechanisms with parallel axes are a form of planar mechanism in which a plate-type driving cam is used to perform transmission between two parallel axes. Of the various indexing mechanisms available (e.g., the Geneva wheel and cylindrical cam), indexing cams with parallel axes are particularly attractive due to their high speed, low noise, low vibration and reliability. Such mechanisms have a low indexing number and a large angular stroke output. As a result, they are ideally suited to applications requiring small stop numbers, such as paper cutting machines, jelly can molding machines and packaging and printing machines.

Peng et al. [1] presented an objective function and set of constraints for optimizing the design of exterior and interior parallel indexing cam mechanisms. Nishioka and Nishimura [2] presented a model for synthesizing an internal parallel indexing cam mechanism with an equally distributed roller follower based on the pressure angle and under cutting constraints. Yan and Chen [3] and Tsay [4] proposed general cam mechanism design methodologies based on enveloping theory and different motion rules. Gonzalez-Palacios [5] presented a unified method for the design of planar and spherical pure rolling mechanisms. Chang et al. [6] proposed a general framework for the geometry design of indexing cam mechanisms. In the proposed approach, screw theory was used to describe the structure of the cam mechanism and the Products of Exponentials Formula (PEF) was used to derive the corresponding kinematic equations. However, the published literature lacks a systematic method for the design and analysis of the indexing cam mechanism with parallel axes.

The current study addresses this deficiency by proposing a simple yet comprehensive integrated design and analysis methodology. The proposed methodology comprises four major steps: (1) the construction of a kinematic model, (2) the derivation of the driving cam profile, (3) the analysis of the kinematic characteristics of the indexing cam mechanism, and (4) the analysis of the pressure angle

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Nomenclature

a_1	center distance of cam and indexing wheel
H	cam head number
I	indexing number
ℓ	roller height
${}^0n$	unit outward normal of cam surface
θ_1	rotation angle of driving cam
θ_2	rotation angle of indexing wheel
θ_h	indexing period of driving cam
R_0	base circle radius of driving cam
R_2	pitch radius of indexing wheel
ρ	roller radius
${}^0S$	driving cam surface
${}^rS$	roller surface
τ_h	angular stroke of indexing wheel
$(xyz)_0$	coordinate frame $(xyz)_0$ built in driving cam
ψ	pressure angle

of the indexing cam mechanism and the principal curvatures of the cam profile. The validity of the proposed methodology is demonstrated by machining an indexing cam on a 3-axis CNC machine.

2. Surface geometry

Indexing cam mechanisms with parallel axes are generally categorized by their head number H, where H typically has a value of 1–4. Moreover, the total number of rollers on the indexing wheel (always an even number) is denoted as z, and typically varies in the range of $z = 4$–16. The indexing number of the cam mechanism, I, is then given by $I = z / H$. Finally, the angular stroke output is defined as $\tau_h = 2\pi H / z$.

This study considered the case of a double head ($H = 2$) indexing cam mechanism, as shown in Fig. 1. In designing the cam mechanism, the profile of the front cam is determined by Rollers 1 and 3, while the profile of the rear cam is determined by Rollers 2 and 4. The two cams have the same shape, but the rear cam is installed upside down such that its datum axis satisfies a fixed angle, θ_p, with the axis of the front cam (see Fig. 2). Note that $\theta_p = 2\pi - \theta_\mathrm{h}$, where θ_h is the indexing period of the cam. To design the cam profile using conjugate theory, the links of the indexing cam mechanism must first be numbered sequentially, beginning with the driving cam (marked as "0" in Fig. 1) and ending with the follower (marked as "2"). Once the frame $(xyz)_\mathrm{i}$ ($\mathrm{i} = 0,1,2$) has been assigned to the link i, the coordinate transformation can be established.

The transformation matrix of frame $(xyz)_1$ with respect to frame $(xyz)_0$ is given by

$$ {}^0T_2 = {}^0T_1{}^1T_2 = \begin{bmatrix} C\theta_1 & -S\theta_1 & 0 \\ S\theta_1 & C\theta_1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} C\theta_2 & -S\theta_2 & 0 \\ S\theta_2 & C\theta_2 & 0 \\ 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} C(\theta_1+\theta_2) & -S(\theta_1+\theta_2) & 0 \\ S(\theta_1+\theta_2) & C(\theta_1+\theta_2) & 0 \\ 0 & 0 & 1 \end{bmatrix}. \tag{1} $$

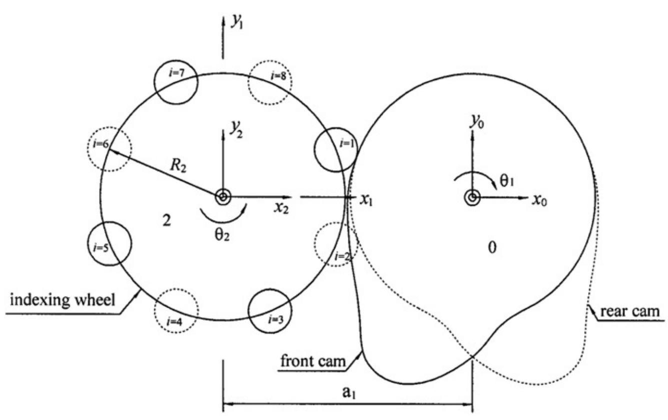

Fig. 1. Indexing cam mechanism.