Dimensional Synthesis of a Watt-II Linkage Using Pareto Optimization

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Abstract

Six-bar linkages have been used for many applications from rehabilitation to military tasks. For instance, a hand rehabilitation robot was designed from the synthesis of a Watt-II six-bar linkage in [1]. On the first loop of the linkage for rehabilitation, dimensional synthesis was used to give full-rotation capability to the input link. On its second loop, an end effector was adjusted to follow the desired movement. A mobile robot was designed in [2] based on a Watt-II linkage. This robot can adapt its modes to fit the terrain with its reconfigurable wheel/track. Most of the research done on six-bar linkage's field is focused on path or motion generation and very few focus on function generation [3]. Therefore, we would like to put our attention on function-generation Watt-II linkages (FGW2Ls).

Traditionally, the mechanism design process has been carried out sequentially in stages. These stages are the problem definition, type synthesis and dimensional synthesis [4]. In the dimensional-synthesis stage, three substages can be differentiated, the kinematic synthesis, kinematic analysis and dynamic analysis. These three substages are also carried out one after another. Please notice that the analysis of the dynamic behavior is typically found at the end of the design process. Moreover, a bad dynamic behavior can cause high dynamic forces on the mechanism [5]. If the results obtained in the dynamic-analysis stage are not satisfactory, recalculation must be done. This leads to undesired loops in the process. However, if the dynamic analysis could be included and somehow quantified into the kinematic synthesis, the number of these undesirable loops could be at least reduced to a minimum. A good way to include the dynamics into the kinematic-synthesis substage seems to be an optimization procedure.

In this work, a method to synthesize a FGW2L with the use of a metaheuristic algorithm is presented. Thus, the dimensional synthesis is realized in MATLAB with consideration of the dynamic analysis. On the side of the kinematics, the linkage is considered as two loops of four-bar linkages, which can be assembled in four different configurations. As constraint, full-rotation capability of the input link at constant angular speed was given with the Grashof condition. On the side of dynamics, forces and stresses are considered with a kinetostatic analysis. Deflections are not calculated directly, but considered proportional to an index developed in [5]. The quantification of the system's eigenfrequency is also included in the methodology with the use of Euler beams. In this situation, the main objective is to approximately fulfill a certain amount of given positions of the output link with respect to the associated positions of the input link, with minimum force. That makes two objective functions. The remaining variables are used as constraints. Because of the number of objective functions, a nondominated sorting genetic algorithm (NDSGA) is used to address the problem. This method gives a pareto solution with multiple different linkages as population.

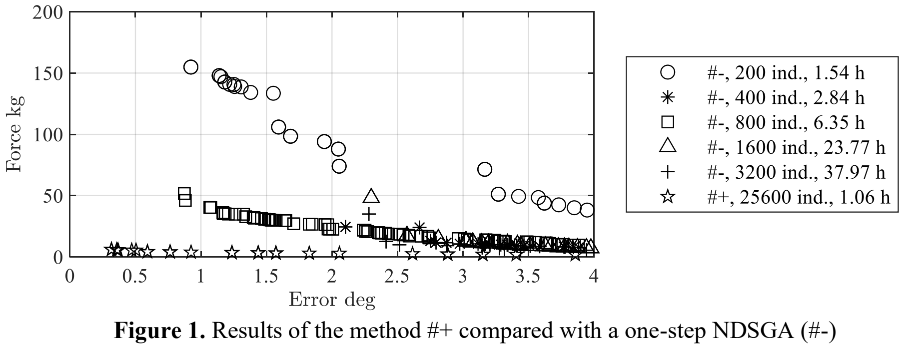

Figure 1. Results of the method #+ compared with a one-step NDSGA (#-)

Two methods for using the NDSGA are presented. The first one (named #-) is applying the algorithm directly to the optimization problem and the other one (named #+) is dividing the problem into three subproblems. The three subproblems are defined as "initial population: kinematic synthesis under force consideration", "adjusting the cross-sectional areas in the initial population" and "multi-objective optimization". Results show that the second method gives a population of synthesized mechanisms with better precision and lower maximum kinetostatic force in less time than the first method. **Figure 1** shows the maximum kinetostatic force on the joints of the FGW2Ls obtained with methods #- and #+. The population on each run and the time spent in solving the problem are indicated in the legend of the graphic.

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