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MODELING A BALL SCREW/BALL NUT
IN SUBSTRUCTURING

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BUTLER ANALYSES

INTRODUCTION

A ball screw/ball nut mechanism causes one part to move with respect to another with a minimum of friction. Such a structure is a good candidate for substructuring by assigning the mating parts to two separate substructures. Figure 1 shows a cut-away photograph of an assembled nut and screw. Matching helical grooves in each share a continuous stream of steel balls which are fed by the screw in the direction of travel through the nut to a conduit that returns the balls to the trailing end for continuous, smooth, quiet operation.
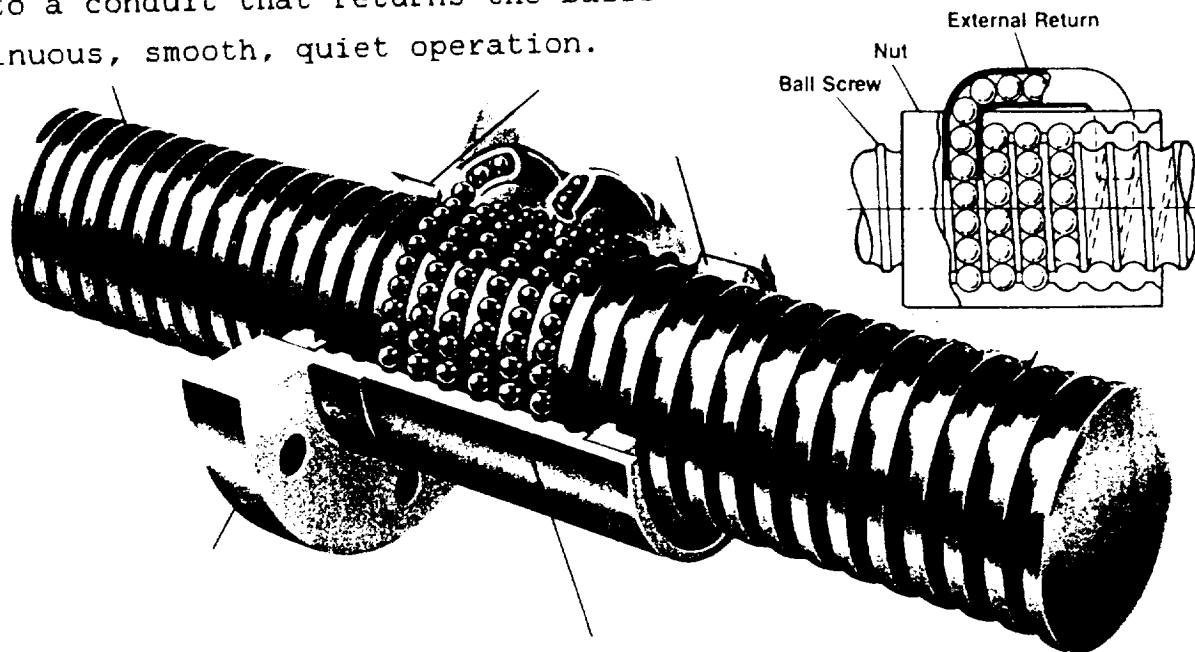

Figure 1

Making a finite element model of this device and coordinating the nut in one substructure with the screw in another substructure is not straightforward. I made several stabs at this before I was satisfied, and decided to share the toils of this challenge at the NASTRAN Colloquium.
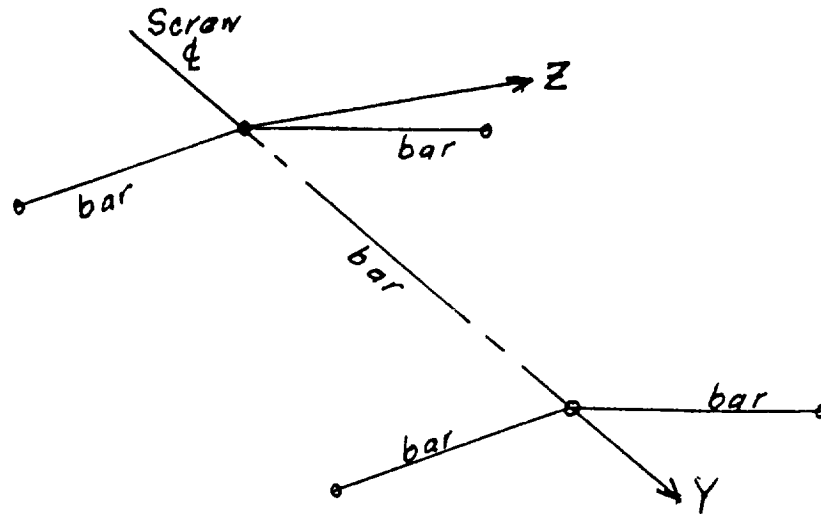
BALL SCREW/BALL NUT

PLAN

In the particular application being discussed here, the screw was attached to the moving structure and the nut was attached to the stationery structure. The object of the overall analysis was to determine the vibration characteristics of the whole structure for various configurations; i.e. the evaluation of the mode shapes and frequencies when parts were moved to different mating positions. Therefore, it was necessary to provide for the ball screw to be moved and reconnected to the ball nut at a number of differenct locations along its length. The Substructure capability in NASTRAN makes it possible to prescribe a connection with a COMBINE operation in Phase 2 and perform an eigenvalue analysis for that configuration. Once these results are catalogued, the analyst erases these results and returns to the COMBINE operation for a new set of connections and performs a second eigenvalue analysis. Succeeding runs can be made for as many repositionings as is desired. The challenge is in modeling the nut so as to represent both the rigid body relation of the helix plus the elastic relations of its members. The scheme then is to model the nut and the screw so as to be invariant for any combination of positions, such that repositioning is achieved by specifying that location on the screw that is to be in contact with the nut in the Phase 2 COMBINE step.

MODEL

The first step is to represent the elastic parts in a simple arrangement. The NUT will consist of two yokes at either end of the nut and an axial tie between the two yokes. The yoke models the nut housing that connects the ball interface to the stationary structure (P). The yoke consistS of two bars extending on either side of the screw (S) centroid to the bolts in P. The sketch shows this simple arrangement.

So far this is pretty boring. It will liven things up to
introduce the rotation of the screw vs. the translation of the
screw. There will be a string of grid points along the screw -
available for connecting to the nut. The nut has 2 grid points
on line with the screw centroid. But these 2 grid points serve
only the elastic function so far. In order to get load into the
nut it needs to be endowed with some rather special things.

When the screw turns it will cause the screw to advance
axially only as a result of its helix reacting the nut. So a
device is used to cause the screw rotation to advance the nut
axially. This does not happen in reality, but it is a device to
provide a loading rate from screw into the nut. The
specifications for the ball nut/screw is one inch of advance for
one full rotation of the screw; i.e. one inch per 2π radians.
This can be imposed with an MPC (Multi - Point - Constraint).
Relating this to the sketch, a unit translation in the Y
coordinate direction of the nut is constrained to 2π (6.2832)
radians of rotation about the Y axis of the screw. But now that
the nut is loaded with this displacement, it must be transformed
into an elastic force which will be reacted into structure P and
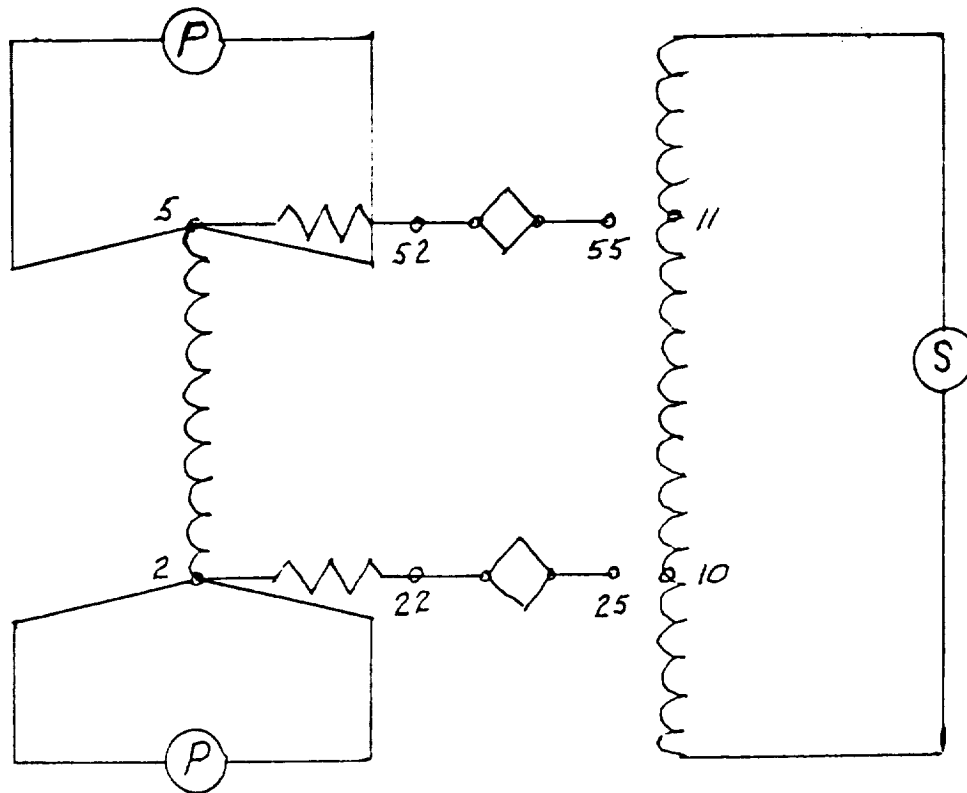then back into an axial force in the screw. In effect what

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needs to be accomplished is to take a rotation of the screw and give it to the nut to intercede then deliver a translation back into the screw. Just saying it, however, doesn't accomplish it, because a number of needs of subsctructure analysis need to be served.

The nut has to be self contained, if it is to be able to be repositioned without having to be remodeled each time. One way is to duplicate a point in the nut to represent the <u>axial rotation</u> of the screw. Then duplicate another point to represent the <u>axial translation</u> of the same point of the screw. Now the helix constraint of the screw via the two special points of the nut can be enacted with the MPC. It operates to connect the translation of the helix elastically into the nut drive point with a spring value equal to the compressibility of the set of balls plus the stiffness of the lands of the helix. This rotation of the screw causes the nut drive point to move axially. Finally, the nut drive point axial translation connects back to the screw axial translation, when the substructures are COMBINE'd.

SUBSTRUCTURE COMMANDS

So far this discussion has been confined to a word description, but more hurdles have to be overcome in finally translating this scheme to problem data. A return to the sketch will be helpful by embellishing it with the screw and assigning numbers to the points. Point 2 of the NUT will connect translational dof's only in to point 10 of the SCREW and similarly point 5 of the NUT will connect translational dof's only to point 11 of the SCREW. However, GP's 2 & 5 will maintain all 6 dof's operational in order to support the link of the yokes to the stationary structure P. As a first step toward incorporating the helical action into the NUT, 2 new pairs of points are introduced.

Points 25 & 55 are added to pick up the rotations of SCREW points 10 & 11. Only rotations about the Y axis will be enabled in GP's 25 & 55 by eliminating dof's 1, 2, 3, 4, & 6 on the GRID bulk card. The pair of points 22 & 52 are inserted to have translational freedom in the Y direction only by eliminating dof's 1, 3, 4, 5, & 6 on the GRID bulk card. The helix is put in place with MPC's between 25(5) and 22(2) and between 55(5) and 52(2) by applying a factor of 2π i.e.

MPC	ID#	22	2	-1.0	25	5	6.2832
MPC	ID#	52	2	-1.0	55	5	6.2832.

Note that GP's 25 & 55 are retained as independent. This is done in order for them to be extant when NUT and SCREW are COMBINE'd later.

All is ready for the introduction of scalar springs between GP 22(2) and GP2(2) and between GP52(2) and GP5(2) to

represent the drive resistance between SCREW and NUT which is carried into the stationary structure by the bars connecting 2 & 5 to GP's 1, 2, 4, & 6. The translational response of NUT drive points 2 and 5 are ready for connecting back to the SCREW in a COMBINE operation.

Now a word about Phase 2 COMBINE operations. If the automatic option for COMBINE is chosen, it finds all dof's at the same physical location and ties all like colocated dof's together unless otherwise inhibited. The substructure control packet will command that substructure P be COMBINE'd with substructrure S. In this case the set of GP's 2, 10, 22, & 25 and the set of GP's 5, 11, 52, & 55 are colocated. It is well to pause to tabulate what the requirements are and what action is needed to implement these desires.

1. Requirements
  GP 2(1,2,3) should tie to GP 10(1,2,3)
  Gp 5(1,2,3) should tie to GP 11(1,2,3).

Remedy
Note is taken that all 6 dof's are active at both points. In order to limit the tie to only translations, the substructure bulk data card called RELES is employed to command the release of dof's 4, 5, & 6 during a COMBINE operation.

2. Requirements
  GP 25(5) should tie to GP 10(5).
  GP 55(5) should tie to GP 11(5).

Remedy
Since GP's 25 & 55 have only dof 5 active and since the requirement is to tie them to dof 5 of GP's 10 & 11 respectively, there is no need to intercede. Allow the automatic option to proceed unhindered.

3. Requirements
  GP 22(2) & 52(2) should not tie to any part of substructure S.

Remedy

Impose a RELES on GP 22(2) & 52(2) to keep them free of any influence from substructure S.

SUMMARY

The action which will ensue from this model is as follows. NUT point GP 25(5) will pick up the rotation from SCREW POINT GP 10(5). The MPC will advance the translation of NUT point GP 22(2) from the rotation of GP 25(5) in the ratio of 1 : 2π. The translation of GP 22(2) will be opposed by the elastic link to the NUT drive point GP 2(2). This helical loading will be carried to the NUT housing bars and reacted into the stationary substructure P. The net translation in all 3 coordinate directions of NUT drive point GP 2 will be tied directly into the 3 translationals of SCREW substructure drive point 10. A parallel set of actions will also take place between GP's SCREW 11 to NUT 55 to 52 to 5 to SCREW 11. This completes the logic.

As a mathematician would say: "This is a pathological case", in that such an elaborate device would not have had to be resorted to for modeling a ball nut, if it were not for the special requirement of having to reposition the NUT with respect to the SCREW. The repositioning requirement demanded that the NUT be self-contained so as to be independent of the relative locations. Thus, in order to be self-contained, the NUT in effect picked up the duties of the helical advancement from the SCREW and carried them out internally in a highly artificial manner in order to transmit the reaction into the parent structure before handing back the results of the helical advancement to the SCREW. As a bonus, this modeling left the analyst free to reposition the NUT at will along the SCREW merely by specifying the coordinate transformation in moving the SCREW to a new position and by specifying new GRID POINT numbers on the RELES cards.

This paper has shown an achievement of a simple set of operating conditions to an otherwise complicated modeling task.