Building the Partial Derivative Machine

We developed the Partial Derivative Machine (PDM) in response to difficulties we encountered in teaching students about mathematical concepts involving partial derivatives and total differentials that are needed in thermodynamics and other areas of physics. The partial derivative machine is a system that has four observable and controllable properties: two forces and two positions. However, only of these four properties only two may be controlled independently. This ambiguity of independent and dependent variables enables the same sort of mathematical flexibility (and confusion) that is present in thermodynamics.

We have developed and used two versions of the Partial Derivative Machine (PDM). The first version of this device is documented in reference 1, and features a central system that is attached to four strings. This document describes the construction of the new version of this device, which is shown below. The new PDM consists of a *fixed* elastic system, which is manipulated by just two strings. Each of these two strings has a scalar position that can be measured with a measuring tape, and a tension that can be adjusted by adding to or removing weights from a hanger.

The PDM is constructed with a particle-board base. Onto this base are attached five binding posts: two for fixing the positions of the two strings, and three nuts to which the system may be attached, as shown in Fig. 2. There are two horizontally oriented pulleys at the top corners of the base (visible in Fig. 2, and the two vertically oriented force-table pulleys that are visible in Fig. 1. Strips of measuring tape are attached to the table to enable convenient measurement of the positions of flags that are attached to the string with binder clips.

The system itself can be constructed in a variety of configurations, some of which are illustrated in Fig. 2. These systems are constructed by tying together strings and springs. For a complete parts list to construct a partial derivative machine, see Table 1.

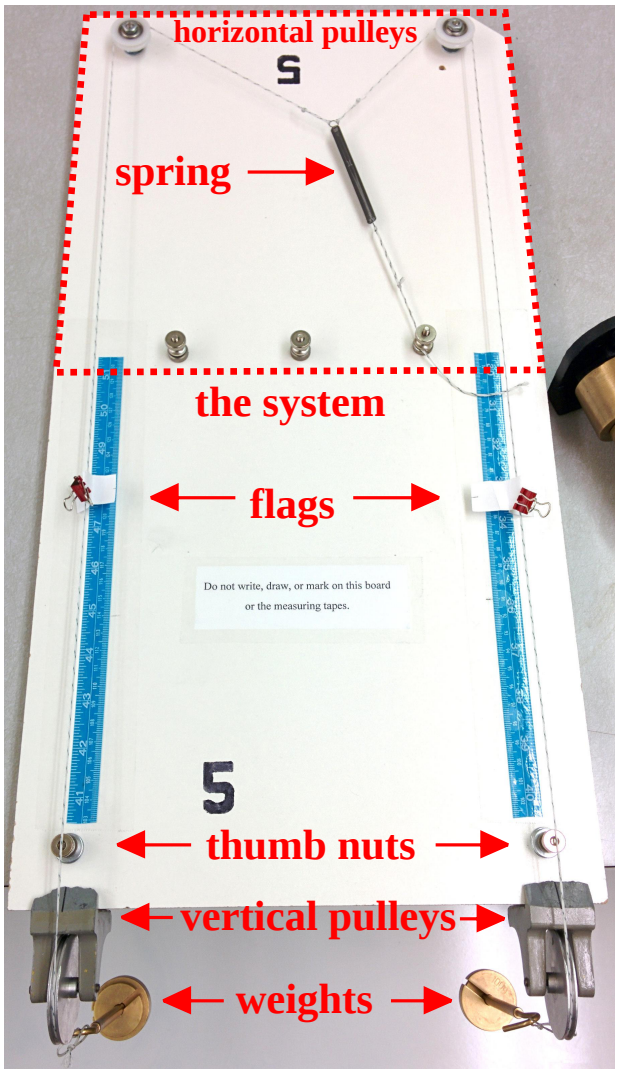

Figure 1: The Partial Derivative Machine. The machine consists of a system which may be manipulated by pulling on two strings. Each string features a flag, which may be used to measure its position, and a weight that can fix the tension in the string. In addition, thumb nuts may be used to fix the position of each string independently.

References

[1] Grant Sherer, Mary Bridget Kustusch, Corinne A. Manogue, and David Roundy. The partial derivative machine. In *2013 PERC Proceedings*, pages 341–344, 2013.

- 3/4" laminated particle board or MDF board, 1'×2'.
- 5 binding posts. Or, #8-32 bolts with washers and knurled thumb nuts. (Knurled nuts, McMaster Carr part number: 92741A120.) We have old metal binding posts that we mostly used.
- Measuring tape (from fabric store)
- 2 (horizontally oriented) pulleys, slipped over bolts for axles. McMaster Carr part number: 3434T14.
- 2 (vertically oriented) force-table pulleys. We got ours from force-table lab experiments. Another possible example: Pasco part number ME-9448B.
- Assorted slotted masses. Pasco part number SE-8704A.
- String. We used Tuf-Line braided dacron. It is best to have low-stretch string.
- Springs, various. One suitable spring would be McMaster part number 9654K516.
- Clear packing tape (to attach the measuring tapes).
- Cardboard box. McMaster Carr part number: 2056T814, with top flaps removed, cut slots for springs, and sprayed flat black.
- 2 binder clips with small pieces of paper for position markers.

Table 1: Parts list for one PDM.

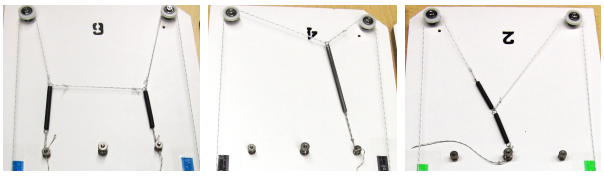

Figure 2: A selection of systems we used in the PDM for class in 2014. In each case the system is anchored to one or more thumb nuts, and consists of a combination of strings and springs that loop around two wheels before exiting the black box. Besides those shown here, we also used systems with no springs, which have a potential energy that is essentially constant—to the extent that the strings are unstretchable. The expert interviews described in this paper were performed with the central example above, which contains a single spring.