THE CONSTRUCTION OF MAP PROJECTIONS BY MODERN METHODS

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The purpose of this article is to explain the construction and operation of the projection ruling machine which has been developed by the Coast and Geodetic Survey. A brief review of other methods of constructing projections will first be given; this will be followed by a general description of the ruling machine, operation procedure and discussion of results.

Part 1

Review of Construction Methods

The accuracy of a finished map depends to a great extent on the projection upon which it is constructed. In the absence of special instruments the usual method of construction has been with the aid of a steel scale, beam compass and straightedge. With such tools it is a tedious task to lay out a projection of high accuracy. Due to this difficulty cartographers have improvised various templates to aid in this work. Information regarding two of these templets can be found in the following references:

The Bumstead Projection Plate (Topographic Instructions of the U. S. Geological Survey, 1928, pages 175-178),
A Projection Plate for Use with Acetate Sheets (Photogrammetric Engineering, Vol. 2, No. 3, page 10).

Each of the plates mentioned above is constructed for one type of projection (such as polyconic); other types would require additional plates. They also have certain limitations as regards scale, projection interval and sheet size. The purpose of each of these plates is to locate the projection intersections on the drafting sheet. These intersections are then connected with a straightedge and the lines ruled in with a pen. A curve is usually drawn as a series of chords rather than a smooth curve. Part of the accuracy of the projection plate is lost in this "hand" drawing process. In spite of these few limitations projection plates will always be useful, especially when the mapping project consists of a regular system of equal size sheets. Also their cheapness and portability make them available for field use.

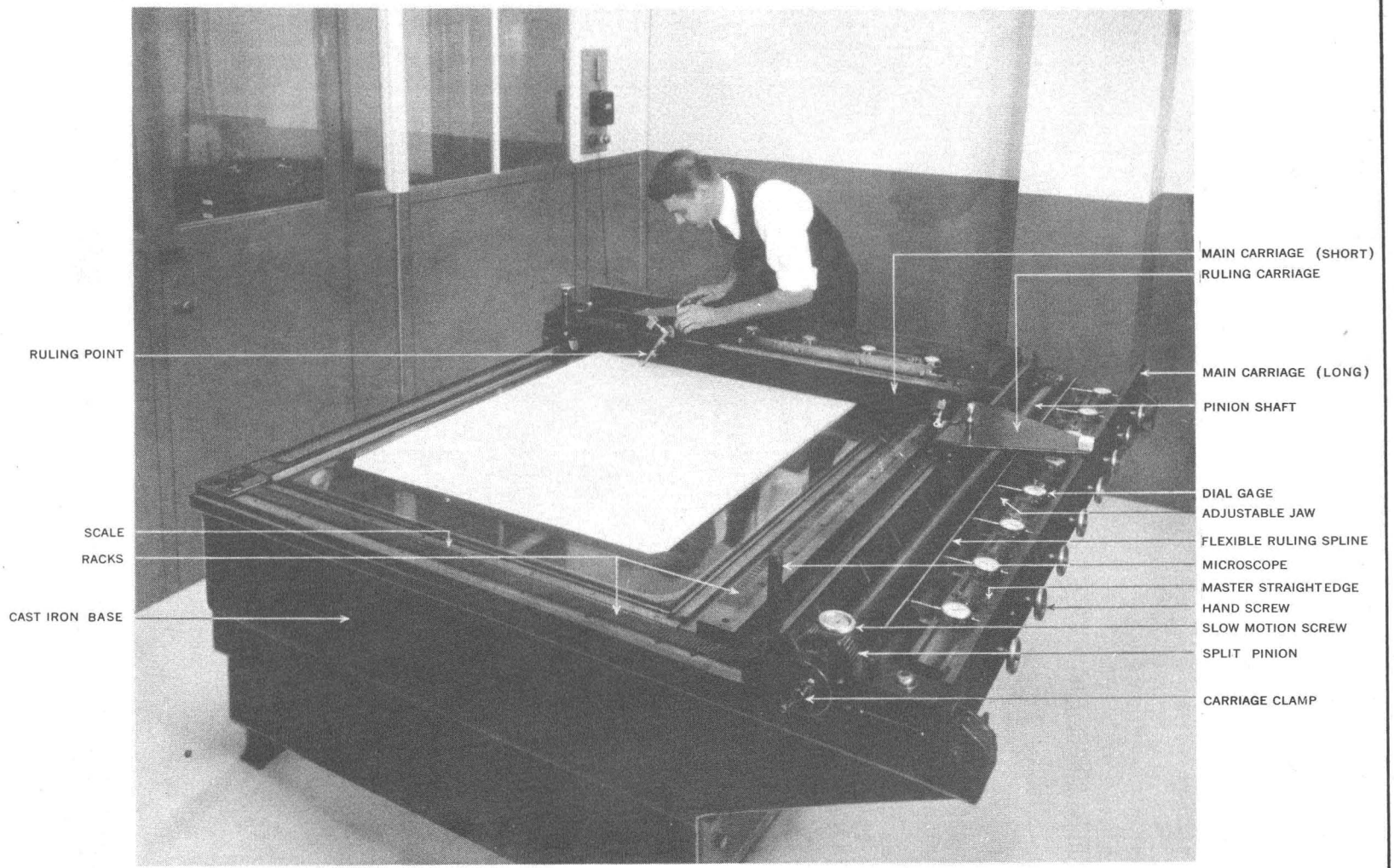
In the U. S. Coast and Geodetic Survey a great many types and sizes of projections are required. The precise ruling machine about to be described is capable of accurately ruling these various types on all kinds of drafting material, such as celluloid, aluminum mounted field sheets, copper plates and paper.

Part 11

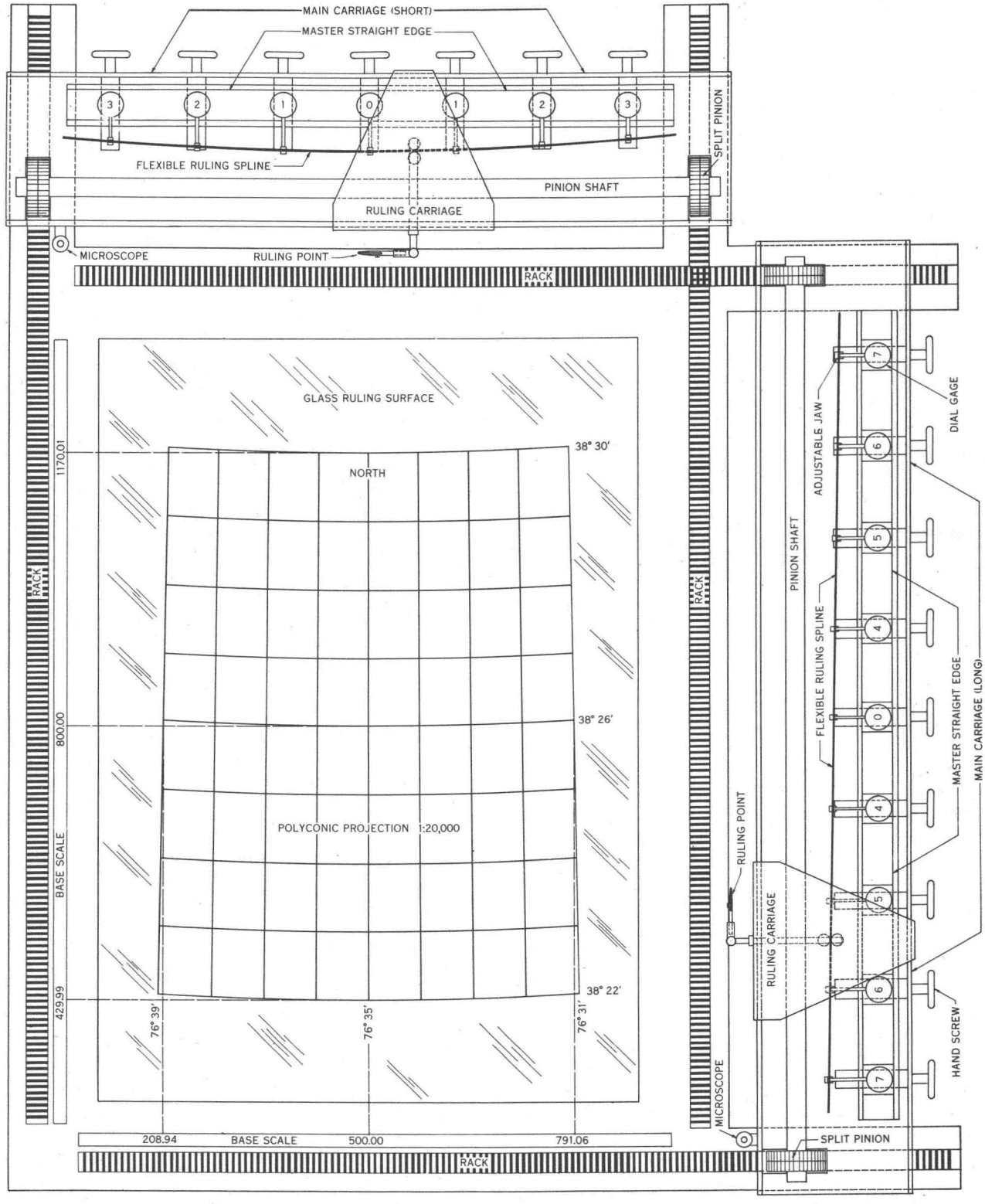
The Projection Ruling Machine of the Coast and Geodetic Survey

A. General description.

The photograph (Fig. A) included in this article shows a general view of the machine. Fig. B is a schematic drawing showing, in plan view, the relation between the flexible ruling splines, base scale settings and the projection itself. The curvature and convergence of the projection lines have been greatly exaggerated for clearness. It is believed that the description will be made clearer if each of the several main parts are discussed individually.



U. S. COAST AND GEODETIC SURVEY
PROJECTION RULING MACHINE
FIG. A.



U. S. COAST AND GEODETIC SURVEY
PROJECTION RULING MACHINE
FIG. B

1. Main Base

The main base consists of a heavy annealed iron casting, mounted on four corner posts. The four top edges of this casting are accurately machined to receive the two pair of precision racks, which guide the motion of the two main carriages. The top of the casting is covered with a three-quarter inch thick glass plate which forms the ruling surface. Six lamps with diffusers are placed beneath this glass to form a "light table." Parallel to the racks on two edges (the forward and the left in photograph) are mounted stainless steel scales subdivided into millimeters which are used in setting the main carriages.

2. Main Carriages.

The two main carriages are of identical construction except one is shorter than the other. These carriages move at right angles to each other and are guided by the racks previously mentioned. The bronze pinions which engage the racks are of the "split" type, thereby insuring that there will be no lost motion and that the movement of the carriages will always be parallel to itself. A flexible ruling spline (spring steel) is mounted in a series of equally spaced adjustable jaws in such a manner that it can be curved or inclined by offsetting each jaw a certain amount. The hand screw attached to each jaw is used in setting the offset and the amount is indicated on one of a series of dial gages. These gages in turn are attached to a master straightedge in such a manner that when all dials read zero the flexible spline is straight and is parallel to the master straightedge. Near the end of each carriage is mounted a microscope which contains an optical vernier reading directly to 0.1 mm with estimation to 0.01 mm. In setting the main carriage it is first rolled to its approximate position, as shown on base scale, and then the final setting is made with the slow motion screw and microscope.

3. Ruling Carriage.

Mounted on each main carriage and traveling parallel to its length is a ruling carriage constructed in such a manner that it transmits the curve set on the flexible spline to the ruling point. This ruling point may be either a pen, a diamond point, or a steel point depending upon what material the projection is drawn.

The machine is of rugged construction and all working parts are made to a high degree of precision. Ball bearings are used in all moving parts. Items such as racks, pinions, tracks, straightedges, etc. are machined to 0.001 inch. The stainless steel scales used for setting the main carriages are of very high accuracy as shown by tests made at the National Bureau of Standards. It was constructed under contract to a design and specifications made by the Coast and Geodetic Survey.

B. Operation Procedure.

Since the polyconic projection is one of the more familiar types it will be used as an example in the present discussion. A brief review of the salient features of this projection will be given to aid those few who may not be familiar with it. Theoretically the projection consists of a series of non-concentric curves, representing parallels of latitude whose radii decrease as the latitude increases; approximately at right angles to these parallels is a series of meridional lines converging towards the pole. These meridional lines are not straight but have a slight curvature. For practical purposes, however, on large scale maps (1:40,000 or larger), the parallels can be made as a series of parallel curves and the meridians as a series of straight lines converging towards the pole.

THE POLYCONIC TABLES "A" AND "B" REFERRED TO BELOW ARE THOSE WHICH HAVE BEEN SPECIALLY COMPUTED FOR THE RULING MACHINE. THESE TABLES GIVE THE OFFSETS TO BE SET ON THE DIAL GAGES FOR VARIOUS VALUES OF CURVATURE AND CONVERGENCE. THE DETAILED STEPS IN THE CONSTRUCTION OF A POLYCONIC PROJECTION WILL NOW BE GIVEN:

EXAMPLE: CONSTRUCT A POLYCONIC PROJECTION ON A SCALE OF 1:20,000, LINES TO BE RULED EVERY MINUTE, AND WITH THE FOLLOWING LIMITS: LAT. 38° 22' TO 38° 30', LONG. 76° 31' TO 76° 39'.

1. FROM POLYCONIC TABLES (SPECIAL PUBLICATION NO. 5, U.S. COAST AND GEODETIC SURVEY) OBTAIN THE VALUE OF ONE MINUTE OF LATITUDE (92.502 MM), ALSO ONE MINUTE OF LONGITUDE IN THE LATITUDE OF THE CENTER PARALLEL WHICH IS 38° 26' (72.765 MM).

2. USING 500 AND 800 MM AS BASE SCALE READINGS FOR CENTRAL MERIDIAN AND PARALLEL RESPECTIVELY (SEE FIG. B), CONSTRUCT A TABLE GIVING SCALE READINGS FOR ALL LINES.

SHORT BASE SCALE

LONGITUDE WEST TO EAST	SCALE SETTING MM
76° 39'	208.94
38'	281.71
37'	354.47
36'	427.24
35'	500.00
34'	572.77
33'	645.53
32'	718.30
31'	791.06

LONG BASE SCALE

LATITUDE SOUTH TO NORTH	SCALE SETTING MM
38° 22'	429.99
23'	522.49
24'	615.00
25'	707.50
26'	800.00
27'	892.50
28'	985.00
29'	1077.51
30'	1170.01

3. FROM POLYCONIC TABLES "A" AND "B" OBTAIN THE FOLLOWING OFFSETS FOR CURVATURE OF THE PARALLELS AND CONVERGENCE OF THE MERIDIANS RESPECTIVELY.

CURVATURE OFFSETS (MM)

DIAL 1	DIAL 2	DIAL 3
0.05	0.20	0.46

CONVERGENCE OFFSETS (MM)

DISTANCE FROM CENTRAL MERIDIAN	DIAL 4	DIAL 5	DIAL 6	DIAL 7
1'	0.04	0.07	0.11	0.15
2'	0.07	0.15	0.22	0.29
3'	0.11	0.22	0.33	0.44
4'	0.15	0.29	0.44	0.58

A SHORT EXPLANATION MIGHT BE DESIRABLE REGARDING THE SETTING OF THE ABOVE OFFSETS ON THE VARIOUS DIALS. ON EACH CARRIAGE THE CENTER OF "ZERO" DIAL (LABELLED "0" IN FIG. B) ALWAYS HAS ITS INDICATING HAND SET ON ZERO. FOR THE PARALLELS OF LATITUDE THE SHORT FLEXIBLE SPLINE IS CURVED BY SETTING PLUS OFFSETS ON DIALS NOS. 1, 2 AND 3 ON BOTH SIDES OF THE "0" DIAL. FOR THE CONVERGENCE OF THE MERIDIANS THE LONG FLEXIBLE SPLINE IS INCLINED TO ITS NORMAL POSITION BY SETTING OFFSETS ON DIALS 4, 5, 6 AND 7, PLUS ON ONE SIDE OF THE

"0" dial and minus on the other side. (In Fig. B the long flexible spline is set for the proper convergence for the western meridian, 76° 39'.)

4. Properly center the drafting sheet on the glass ruling surface and tape edges securely.

5. Set ruling spline on the short main carriage to the proper curvature.

6. Roll the short main carriage over the ruling surface to a scale reading of 429.99 mm and draw the southernmost parallel. Move the carriage to the other scale readings (522.49, 615.00, etc.) until all parallels are drawn.

7. Roll the long main carriage (which is at right angles to short carriage) over the ruling surface to a scale reading of 500.00 mm and draw the central meridian, longitude 76° 35'. Then set the convergence offsets (for 1 minute) on the flexible spline, move the carriage to a scale reading of 427.24 mm and draw the meridian corresponding to longitude 76° 36'. Repeat this procedure for each meridian.

Projections other than polyconic are constructed in a similar manner except different offset tables are used. In the case of a Mercator projection which consists of a series of straight lines at right angles to each other, the flexible spline is made straight by setting all dial gages to read zero.

C. Discussion of Results.

The ruling machine was first put in operation about three years ago. Since that time several hundred projections of various types and sizes have been constructed on low shrinkage celluloid, copper, aluminum mounted sheets and paper. This experience indicates that projections can be constructed more accurately and in less than half the time required by the usual hand methods. Computations similar to those tabulated in this paper are required for each projection. With the aid of special tables and an adding machine these values can be compiled in less than half an hour.

In regard to accuracy, it is believed that the machine will rule a line within 0.05 mm of its true position. The maximum sheet size which can be mounted on the ruling surface is 40" x 50". In regard to scale limits, the ruling splines are sufficiently flexible to take care of the curvatures in scales as small as 1:500,000.

The machine also has been found very useful for superimposing state plane coordinate grids on completed projection sheets, the usual procedure being to plot the geographic positions of four grid intersections (forming a rectangle as large as possible). These intersections are used for orienting the sheet on the glass ruling surface. The sheet is then taped to the glass and the grid lines ruled in the usual manner.

Recently some attention has been given to plotting control points with the machine. These points are plotted immediately after the projection is ruled and while the sheet is still taped to the ruling surface. The location of the control point is shown as a small inked intersection.

Typographical Error

It is very much regretted that through a typographical error, the name Ralph Moore Perry appeared instead of the correct Ralph Moore Berry, the author of the discussion and illustration of Mr. Wilson's paper on Plane Coordinate Systems on page 12 and the title page of Photogrammetric Engineering, Volume III, Number 3.