

SHEET FEED ASSEMBLY DEFINING CURVED AND STRAIGHT FEED PATH

FIELD OF THE INVENTION

5 The present invention relates to feeding sheets of material along a feed path that has curved sections that transition into a straight section or other, differently curved sections. In particular, the invention relates to feeding sheets of paper through an inkjet printer.

BACKGROUND OF THE INVENTION

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At first glance, a observer may conclude that there is relative freedom in the shape a paper feed path may take, however there are some general rules which must be obeyed for a sheet of paper to be able to conform to a paper guide. If the paper cannot conform to the shape of the guide, it is not actually being "guided". This can lead to undesirable print artefacts.

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First (and most obviously): the path must not have any step jumps in it. Even minute steps cause the paper to jam during threading and can cause print artefacts as the trailing edge flicks on passing. The paper cannot conform to a step jump. In mathematical terms, the path must be continuously differentiable.

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Second: At all points along the curve the slopes (tangents to the path) must match. This means the path cannot have sharp kinks in it where the radius of curvature is essentially zero. Again, quite clearly, the paper cannot conform to a sharp bend. Mathematically this means the first differential (tangents) at the transition points from one type of curve to another must also be equal.

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Third (and not so obvious): At any point along the path, the instantaneous radii of curvature must not have step jumps, or the paper will not conform to the guide.

This is illustrated by the general bending equation:

$$R = EI/M$$

Where: R is the radius of curvature

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E is the materials bending modulus

I is the second moment of area

M is the applied bending moment

A step jump in radius of curvature requires a step jump in M , the bending moment, since the other variables are fixed properties of the media. However, it is not physically possible to apply such a step in the moment. In reality, the path has a smoothly varying instantaneous radius of curvature at all points. For example, a guide with an arc of constant curvature leading to a tangential straight part, has a constant arc portion, where R is constant and finite, and consequently M is constant and finite. In the straight portion, R is infinite, so the bending moment $M=0$. However at the transition point both conditions must exist simultaneously. This is a contradictory condition and, as a result, the paper cannot stay in contact with the guide at such a point.

Many fields of industry require sheet material to be moved along a feed path. If the feed path is curved, it is exceedingly difficult to bend the extreme leading edge into the curved shape. As the leading edge contacts the guides or rollers that define the curve in the feed path, the contact force acting at the edge bends the sheet because of the bending moment the force creates. However, at a distance extremely close to the edge, the moment arm (i.e. the distance to the point where force is applied) is not long enough to generate the bending moment necessary for the sheet to flex into the curved shape defined by the guides. At distance infinitesimally close to the leading edge, the moment arm is infinitesimally small and the sheet is in fact flat; not curved at all. Hence there is a relatively flatter leading edge as the sheet is fed around the defined curve. This gives the leading edge a tendency to 'chisel' into the guide surface because it is not conforming to the curve. The chiselling action increases friction and can be the driving mechanism behind feed jams. Feeding sheets of paper through a printer is an example where jams, or 'paper cockle', in the sheet feed system are a common problem.

Often it will be necessary for the sheet feed path to be curved and subsequently transition into a straight line. At these points of transition in the feed path, the sheet material is prone to deviate from the nominal or ideal path. As discussed above, this is particularly so of the leading and trailing edges of the sheet. The stiffness in the sheet causes it to deviate from the feed path until the leading edge enters the nip of a downstream roller pair (or guide surface) while the trailing edge can spring away from the feed path once it is released from between a roller pair.

If the sheet is subject to a surface treatment such as the coatings on high quality photo papers, this deflection from the nominal feed path can be especially detrimental. Inkjet printing requires the media substrate to stay on the feed path for optimum print quality. If the leading or trailing edge of the media sheet deviates from the feed path, then the distance from the nozzles to the surface of the sheet will change. Varying the flight time of the ink droplets will result in visible artefacts in the resulting print.

The invention is well suited to paper feed assemblies in inkjet printers. In light of the wide spread use of inkjet printers, the invention will be described with reference to this particular application. However the ordinary worker will appreciate that the invention is equally relevant to other applications involving sheet feed mechanisms and the broad inventive concept is not restricted to the field of inkjet printers.

SUMMARY OF THE INVENTION

According to a first aspect, the present invention provides a sheet feed assembly for feeding sheets of material having a known bending stiffness, the sheet feeding assembly comprising:

feed path structures for defining a feed path, the feed path having a curved section connected to a straight section such that the straight section is downstream of the curved section with respect to the sheet feed direction; wherein,

the curved section and the straight section meet at a transition point where the straight section is tangential to the curved section and configured such that a sheet partially in the curved section and partially in the straight section has zero bending moment at the transition point and zero bending moment in any part on the straight portion.

By transitioning to the straight section of the feed path at a point where the sheet inherently has zero bending moment as it passes along the feed path, the leading edge and the trailing edge has no driving mechanism to deviate from the paper path. The unconstrained leading and trailing edges follow the straight feed path like the constrained intermediate portions of the sheet. In this way, the printing gap between the nozzles and the surface of the media sheet remains constant.

Preferably, the feed path structures include a roller pair positioned such that its nip is at the transition point. Preferably, the feed path structures include a roller partially defining the curved section of the feed path.

5 Optionally, the curved section has an upstream end where the feed direction is parallel to and opposite the feed direction at the transition point. Optionally, the feed structures include a chute extending between the upstream end and the transition point, the chute having an inner curved surface nesting within an outer curved surface to define a gap between the inner and outer curved surfaces through which the sheets are fed. Optionally, the inner and the
10 outer curved surfaces are identical and displaced from each other to form the gap. Preferably, the inner and outer curves are identical to a bending curve adopted by at least part of a sheet that is bent over and held by co-planar and directly opposing forces such that tangents at both ends of the bending curve are parallel to each other and spaced apart by the spacing between the upstream end and the transition point.

15 Preferably, the feed path extends through an inkjet printer. In a further preferred form, the inkjet printer has a printhead positioned adjacent the feed path downstream of the transition point. In a particularly preferred form, the upstream end of the chute receives sheets sequentially fed from a stack of the sheets by a picker arm.

20 BRIEF DESCRIPTION OF THE DRAWINGS

 Specific embodiments will now be described by way of example only to illustrate the present invention, with reference to the accompanying drawings, in which:

25 Figure 1 is a schematic representation of a sheet feed assembly in an inkjet printer according to the prior art;

 Figure 2 is a diagram of a cantilevered simple beam deflecting under a load applied to
30 its end;

Figure 3 is a schematic representation of a sheet feed assembly for an inkjet printer with rollers positioned using the simple beam analysis of Fig. 2;

5 Figure 4 is a diagram of a sheet being bowed by co-planar, opposing forces until its ends are parallel;

Figure 5A is a plot of a curve conforming to the shape of the bowed sheet in Fig. 4;

Figure 5B is an enlarged diagram of the incremental secant line, dy , dx and θ at a point on the curve plotted in Fig. 5A;

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Figure 6 is a plot of a curve conforming to the shape of a sheet bowed by co-planar, opposing forces with nonparallel ends;

15 Figure 7A is schematic representation of a C-chute in accordance with the curve plotted in Fig. 6;

Figure 7B is an enlarged diagram of the resolution of the force acting at the feed roller pairs into normal and tangential components;

20 Figure 8 is a section view of an inkjet printer incorporating a C-chute shaped to conform to the curve plotted in Figure 5A;

Figure 9 is an exploded perspective of the printhead cartridge used in the printer of Figure 8;

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Figure 10 is a section view of the print engine used in the printer of Figure 8; and,

Figure 11 is a schematic representation of a sheet feed assembly according to the invention with a curved chute shaped to correspond to the curve plotted in Fig. 5A.

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DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

SHEET FEED CHUTE CONFORMING TO SHAPE OF BOWED SHEET

Referring to Figure 1, a sheet feed assembly is shown feeding a sheet 26 of media substrate past a printhead 2. The feed path 8 is extends around an idler roller 14 and through the nip 16 of input drive rollers 4 and 6. The input drive rollers drive the sheet 26 past the printhead 2 and into the nip 18 of the exit rollers 22 and 24.

The inherent bending stiffness in the sheet 26 causes the leading edge to deviate away from the feed path 8 as it leaves the idler roller 14 and the guiding shroud 12. The input drive rollers 4 and 6 draw the sheet into the nip 16 and therefore back on to the feed path 8. However, the input drive rollers 4 and 6 are mounted so that the opposing pinch force from each roller are normal to the straight part of the feed path 8. This does nothing to redirect the sheet back to the feed path.

The leading edge of the sheet 26 continues to deviate as it crosses the printzone 20 of the feed path 8. The printing gap between the printhead 2 nozzles and the feed path 8 is X. The printing gap between the nozzles on the printhead 2 and the leading edge is X' – significantly smaller than X. Therefore the flight time of the droplets onto the leading edge will be shorter than the droplet flight time once the sheet 26 enters the nip 18 of the output rollers 22 and 24, and draws the sheet back to the feed path 8. The variation of droplet flight times affects dot spacing on the printed sheet resulting in visible artifacts in the print.

Referring to Figure 2, the sheet 26 has been modeled as a simple cantilever beam loaded at its end (or a distance L from the fixed end). The radius of curvature changes along the beam 26 until it reaches infinity at the free end. That is, the beam is flat at the very end, as the load F has no moment arm to bend it. If the beam 26 were to extend beyond the point where F is applied, it would follow the tangent 8 (again, no moment to bend it).

The radius R of the curvature at any point on the beam 26 can be calculated using:

$$R = EI/M$$

where:

R is the radius of curvature of the beam at any given point along its length;

E is Young's modulus of the sheet material;

M is the ending moment at that point on the beam; and,

I is the second moment of area about an axis across one surface of the sheet.

- 5 Using this model, it is also possible to determine T, the distance between the intersection of the tangent 8 on the wall 28 and the centre of radius R, and the angle θ between the wall and a normal to the tangent 8.

Referring to Figure 3, the cantilever beam model of Figure 2 is used to configure the
10 feed path structures. The roller 14 has a radius R equal to that calculated in the beam model. The tangent line 8 becomes the flat section of the feed path extending past the printhead 2. L, T and θ are used to position the centre of the roller 14 and the nip 16 between the input drive rollers 4 and 6. As the sheet 26 is fed through the input drive rollers 4 and 6, it has no bending moment at that point, and no bending moment at any point downstream (with respect to feed
15 direction 10). Accordingly, the sheet 26 inherently follows the flat feed path 8.

The output rollers (not shown) and downstream feed path structures (not shown) can be similarly positioned relative to each other to avoid the trailing edge from flicking up or
20 down when it is released from the input drive rollers 4 and 6.

Figure 4 is a sketch of a sheet 26 bowed by coplanar, opposing forces F until the ends
30 are parallel to each other. The shape of the bowed sheet 26 can be determined iteratively using the three equations set out below. Using the shape provided by this model, it is possible to form a theoretically frictionless C-shaped chute. The chute is theoretically frictionless
25 because it dresses to exactly the same shape as the bowed sheet and therefore, there is no normal force at any points of contact between the sheet and the chute surface.

CURVATURE OF BOWED SHEET

30 Referring to Figure 5A, the curve of the sheet 30 is shown with its axis of symmetry (corresponding to the surface of the wall 28 shown in Figure 4) on the X axis. Angle θ is scribed between R (the radius of curvature at any point) and the horizontal. Force F is applied

by rollers at the point 100 that the sheet transitions from a curved to a straight feed path. At this point on the curve, $x_{\max}$ is found analytically (where $\theta=90^\circ$). As best shown in Figure 5B, ds is the secant line at a point on the curve for given θ .

5 Find $x_{\max}$:

$$ds = \frac{dx}{\sin \theta} = \frac{EI}{F} \frac{d\theta}{(x_{\max} - x)}$$

$$10 \quad (x_{\max} - x)dx = \frac{EI}{F} \sin \theta \, d\theta$$

$$\therefore \int_0^{x_{\max}} (x_{\max} - x)dx = \frac{EI}{F} \int_0^{\frac{\pi}{2}} \sin \theta \, d\theta$$

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$$\int_0^{x_{\max}} x_{\max} dx - \int_0^{x_{\max}} x dx = -\frac{EI}{F} [\cos \theta]_0^{\pi/2}$$

$$x_{\max}^2 - \left[\frac{x^2}{2} \right]_0^{x_{\max}} = \frac{EI}{F}$$

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$$x_{\max}^2 - \frac{x_{\max}^2}{2} = \frac{x_{\max}^2}{2} = \frac{EI}{F}$$

$$\therefore x_{\max} = \sqrt{2 \frac{EI}{F}}$$

25 **Numeric solution for the complete shape of the proposed curve:**

Using the above equation: for a given input value of $x_{\max}$, we can solve $\frac{EI}{F}$

Then from:

$$ds = R d\theta$$

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$$R = \frac{EI}{M}$$

$$M = F(x_{\max} - x)$$

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$$1. \quad \therefore ds = \frac{EI}{F} \frac{d\theta}{(x_{\max} - x)}$$

$$2. \quad dx = \sin \theta \times ds$$

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$$3. \quad dy = [ds^2 - dx^2]^{\frac{1}{2}}$$

By iterating 1 □ 2 □ 3 in a computational loop and vector summation, we can produce the correctly shaped curve. Knowing the correct shape for a given $x_{\max}$ may not be sufficient, since it is usually important that the distance $2y_{\max}$ between the curves tips matches into the path system. We can solve this problem using a “shooting” method. We can do a binary search to iterate $x_{\max}$ and rerun the algorithm to find the value of $2y_{\max}$ for the correct curve to fit the design boundary conditions.

25 Also of interest is the minimum radius of curvature of this shape, because it suggests when the media will retain a permanent set:

R_0 when $x = 0$ i.e. the minimum radius of the curve and the maximum bending moment.

Referring again to Figure 5A, the first boundary condition 98 is $x = 0$, where $R = R_0$ and $\theta = 0$.

The second boundary condition 100 is $x = x_{\max}$, R is infinite and $\theta = 90^\circ$. Between these boundary conditions, the curved feed path is a transition section 102 along which the radius
 5 varies in accordance with a sheet of material constrained at those boundary conditions.

NON-PARALLEL ENTRY AND EXIT PATHS

In some situations, the feed path does not turn the sheet through a full 180 degrees.

10 Referring to Figure 7A, the ends 30 of the sheet 26 are not parallel. The first and second feed rollers 50 and 52 hold the ends 30 at an angle to each other and exert a buckling force F on the sheet 26. The C-chute inner surface 34 and the outer surface 32 conform to the buckled shape of the sheet 26 and if the rotation of the first and second feed rollers 50 and 52 is synchronized, there is theoretically no friction between the sheet 26 and the chute. This
 15 requires close control of the feed rollers 50 and 52 such that the co-linear, opposing buckling forces F can each be resolved (see Figure 5B) into a force F_n acting normal to the sheet and F_s acting parallel to the plane of the ends 30. If the magnitude of F_s is the same at each of the feed rollers 50 and 52, the sheet 26 does not scrub against the inner or outer surface 34, 32 of the C-chute 54.

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As shown in Figure 6, the numeric calculation method for determining the curve of a buckled sheet is the same as for a sheet buckled until its ends 30 are parallel (see Figure 4) except the boundary condition becomes $\theta < 90^\circ$.

25 The same equations and method for the numeric solution described above still hold true, but the analytic solution to solve for $x_{\max}$ becomes:

$$M = F(x_{\max} - x)$$

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$$= \frac{EI}{R}$$

$$\frac{EI}{RF} = (x_{\max} - x)$$

where:

- 5 R is the radius of curvature of the sheet at any given point along its length;
 E is Young's modulus of the sheet material;
 M is the ending moment at that point in the sheet; and,
 I is the second moment of area about an axis across one surface of the sheet.

$$10 \quad \frac{EI \sin \theta \, d\theta}{F} = (x_{\max} - x) dx$$

$$dx = \sin \theta \, ds$$

$$15 \quad R \cdot d\theta = ds$$

$$R = \frac{dx}{\sin \theta \, d\theta}$$

- 20 Iterating through equations 1 $\rightarrow$ 2 $\rightarrow$ 3 set out above in a computational loop and then vector summing:

$$x_{\max} = \sqrt{\frac{2EI}{F} [1 - \cos \theta_{\max}]}$$

- 25 Interestingly:

R_0 when $x = 0$ i.e. the minimum radius of the curve and the maximum bending moment

$$\begin{aligned}\therefore M_0 &= F(x_{\max} - x) \\ &= F x_{\max}\end{aligned}$$

$$\therefore R_0 = \frac{EI}{M_0} = \frac{EI}{F x_{\max}} = \frac{x_{\max}^2}{2x_{\max}}$$

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$$= \frac{x_{\max}}{2}$$

Hence, the circle of minimum radius R_0 has a diameter = $x_{\max}$.

10 SHEET FEED FOR HIGH SPEED PRINTER

A C-chute is useful in an inkjet printer to create a paper path between a feed tray at the base of the printer and a collection tray formed by the top surface the printer. This is a compact configuration with a small footprint. Figure 8 is a section view of a printer 66 with this configuration. This printer uses a print engine shown in copending USSN 12/014772 (Our Docket RRE017US), the contents of which are incorporated herein by cross reference. The print engine of a printer refers to the key mechanical structures of an inkjet printer. The peripheral structures such as the outer casing, the paper feed system, paper feed and collection trays and so on are configured to suit the specific printing requirements of the printer (for example, photo printer, network printer or SOHO printer). The printer shown in Figure 8 is an A4 SOHO printer.

Figure 10 shows a section view of the print engine 3 with a sheet of media 26 extending past the printhead integrated circuit (IC) 64. The printhead 2 is in the form of a removable printhead cartridge 70. Figure 9 is an exploded perspective of the printhead cartridge 70 showing the top molding 72 with a central web 74 for structural stiffness and to provide textured grip surfaces 76 for manipulating the cartridge during insertion and removal. Ink from the ink tanks 56 (see Figure 8) is fed to the inlet manifold 82. The inlet manifold

has five inlet ink spouts 88 set in an inlet shroud 78. Each of the inlet spouts 88 feed a respective longitudinally extending channel (not shown) in the liquid crystal polymer (LCP) molding 92. Air cavities 94 above the channels damp any hydraulic hammer in the ink when printing stops abruptly. A series of printhead integrated circuits (IC's) 64 are mounted to the underside of the LCP molding 92. The printhead IC's 64 define an array of ink ejection nozzles (not shown) that extend the width of the sheets 26 to be printed. Hence, the printer is a pagewidth printhead that remains stationary in the printer during printing.

At the downstream end of the LCP molding 92 is the outlet manifold 84. It has five outlet ink spouts 90, each fluidically connected to one of the longitudinally extending ink channels respectively. The outlet shroud 80 is configured to allow the outlet spouts 90 to engage an outlet interface 96 (see Figure 10) which feed to a sump 86 (see Figure 8). The sump 86 is used when the printer fluidic system actively primes or deprimers the printhead 2. Detailed description of the fluidic system is provides in the Applicant's USSN 11/872719 (our docket SBF009US) the contents of which is incorporated herein by reference.

In the interests of clarity, Figure 11 is sketch of the printer 66 showing the operation of the C-chute 54 in relation to the straight feed path 8 in the print zone 20. The C-chute 54 has an inner surface 34 and an outer surface 32. The geometries of the inner surface and the outer surface are the same with the exception of the upstream and downstream end portions where the inner surface is reduced and or the outer surface is expanded to accommodate the thickness of the sheet and some tolerance. The majority of the gap between the inner and outer surfaces is due to displacement of the inner 34 relative to the outer 32 along the C's central line of symmetry.

In operation, paper sheets 26 are sequentially fed from the stack 40 in the paper tray 38 by the picker arm 36 into the C-chute feed rollers 46 and 48. The sheets 26 enter the C-chute 54 and the outer surface 32 guides the leading edge around. The geometry of the outer surface 32 is such that the leading edge easily feeds into and conforms to the curve. Contact forces acting at the leading edge to bend the sheet into the necessary shape have a long lever arm to the point where the sheet contacts the inner surface 34.

As discussed above, the feed path 8 at the entry and exit to the C-chute is parallel. Hence, the leading edge does not deviate from the straight path 8 as it is fed through input drive rollers 4 and 6. The sheet continues along the path 8 directly into the nip 18 of the output rollers 22 and 24. The printed sheets 44 drop from the output rollers into the collection
5 tray 42.

Precise synchronization of the C-chute feed rollers 46, 48 and the input drive rollers 4 and 6, makes the chute theoretically frictionless. The two roller pairs are feeding the sheet 26 in parallel but opposing directions. The curvature of the sheet 26 between the roller pairs is
10 the curvature that the sheet wants to adopt naturally. Hence, there is no normal force component to any contact between the sheet and the inner or outer surface, and therefore no friction.

The invention has been described herein by way of example only. The ordinary
15 worker will readily recognize many variations and modifications which do not depart from the spirit and scope of the broad inventive concept.

CLAIMS

1. A sheet feed assembly for feeding sheets of material having a known bending stiffness, the sheet feeding assembly comprising:

5 feed path structures for defining a feed path, the feed path having a curved section connected to a straight section such that the straight section is downstream of the curved section with respect to the sheet feed direction; wherein,

the curved section and the straight section meet at a transition point where the straight section is tangential to the curved section and configured such that a sheet partially in the
10 curved section and partially in the straight section has zero bending moment at the transition point and zero bending moment in any part on the straight portion.

2. A sheet feed assembly according to claim 1 wherein the feed path structures include a roller pair positioned such that its nip is at the transition point.

15 3. A sheet feed assembly according to claim 1 wherein the feed path structures include a roller partially defining the curved section of the feed path.

4. A sheet feed assembly according to claim 1 wherein the curved section has an
20 upstream end where the feed direction is parallel to and opposite the feed direction at the transition point.

5. A sheet feed assembly according to claim 4 wherein the feed structures include a chute extending between the upstream end and the transition point, the chute having an inner curved
25 surface nesting within an outer curved surface to define a gap between the inner and outer curved surfaces through which the sheets are fed.

6. A sheet feed assembly according to claim 5 wherein the inner and the outer curved surfaces are identical and displaced from each other to form the gap.

30 7. A sheet feed assembly according to claim 6 wherein the inner and outer curves are identical to a bending curve adopted by at least part of a sheet that is bent over and held by co-

planar and directly opposing forces such that tangents at both ends of the bending curve are parallel to each other and spaced apart by the spacing between the upstream end and the transition point.

5 8. A sheet feed assembly according to claim 7 wherein the feed path extends through an inkjet printer.

9. A sheet feed assembly according to claim 8 wherein the inkjet printer has a printhead positioned adjacent the feed path downstream of the transition point.

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10. A sheet feed assembly according to claim 9 wherein the upstream end of the chute receives sheets sequentially fed from a stack of the sheets by a picker arm.

11. A sheet feed assembly for feeding sheets of material having a known bending stiffness,
15 the sheet feeding assembly comprising:

feed path structures for defining a feed path, the feed path having a first point with a first radius of curvature, a second point with a second radius of curvature and a transition section extending between the first point and the second point; wherein,

the transition section defines conforms to a shape adopted by one of the sheets of
20 material extending from the first point where it has a curvature of the first radius, to the second point where it has a curvature of the second radius.

12. A sheet feed assembly according to claim 11 wherein the feed path in the transition section is determined analytically using the first point and the first radius of curvature as a first
25 boundary condition and the second point and the second radius of curvature as a second boundary condition.

13. A sheet feed assembly according to claim 11 further comprising a first sheet feed drive roller pair and a second drive roller pair for feeding the sheet along the feed path wherein the
30 first drive roller pair and the second drive roller pair are configured for synchronous operation.

14. A sheet feed assembly according to claim 11 wherein the feed path at the first point is normal to the feed path at the second point.

5 15. A sheet feed assembly according to claim 14 wherein the feed structures include a chute extending between the first point and the second point, the chute having an inner curved surface nesting within an outer curved surface to define a gap between the inner and outer curved surfaces through which the sheets are fed.

10 16. A sheet feed assembly according to claim 15 wherein the inner and the outer curved surfaces are identical and displaced from each other to form the gap.

17. A sheet feed assembly according to claim 16 wherein the feed path extends through an inkjet printer.

15 18. A sheet feed assembly according to claim 17 wherein the inkjet printer has a printhead positioned adjacent the feed path downstream of the second point.