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ON STARLIKENESS AND CONVEXITY OF CERTAIN MULTIVALENT FUNCTIONS

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Abstract

The object of the present paper is to determine the radii of starlikeness and convexity of order α of certain analytic multivalent functions with a kind of bounded argument.

1. Introduction

Let p, α, β and r denote $p \in N = \{1,2,3,\cdots\}$, $0 \leq \alpha < p$, $\beta > 0$ and $0 < r \leq 1$, respectively. Let U_r denote the set $\{z: |z| < r\}$ and let U denote the unit disk U_1. Next, let A_p denote the class of functions of the form :

(1.1) $$f(z) = z^p + \sum_{n=p+1}^{\infty} a_n z^n$$

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which are analytic in the unit disk U. We denote A_1 by A.

A function $f(z)$ in the class A_p is said to be p-valently starlike of order α in U_r if and only if it satisfies

$$\text{(1.2)} \qquad \mathrm{Re}\left\{ \frac{z f'(z)}{f(z)} \right\} > \alpha \qquad (z \in U_r).$$

We denote by $S_p^*(\alpha)_r$ the subclass of the class A_p consisting of all p-valently starlike functions of order α in U_r.

Further, a function $f(z)$ in the class A_p is said to be p-valently convex of order α in U_r if and only if it satisfies

$$\text{(1.3)} \qquad \mathrm{Re}\left\{ 1 + \frac{z f''(z)}{f'(z)} \right\} > \alpha \qquad (z \in U_r).$$

Also, we denote by $K_p(\alpha)_r$ the subclass of the class A_p consisting of all p-valently convex functions of order α in U_r.

Let M be the class of functions of the form :

$$\text{(1.4)} \qquad p(z) = 1 + \sum_{n=1}^{\infty} c_n z^n$$

which are analytic in the unit disk U.

A function $p(z)$ in the class M is said to be a member of the class $M(\beta)$ if and only if it satisfies

$$\text{(1.5)} \qquad | \arg p(z) | < \frac{\pi \beta}{2} \qquad (z \in U).$$

Finally, a function $f(z)$ in the class A_p is said to be p-valent strongly close-to-convex of order α and type β in U_r if and only if there is a function $g(z) \in K_p(\alpha)_r$ such that $\frac{f'(z)}{g'(z)} \in M(\beta)$. We denote by $C_p(\alpha, M_\beta)_r$ the subclass of the class A_p consiting of all p-valent strongly close-to-convex functions of order α and type β in U_r.

In particular, whenever the numbers p, α, β and r mentioned in technical terms $S_p^*(\alpha)_r$, $K_p(\alpha)_r$ and $C_p(\alpha, M_\beta)_r$ are equal to 1, 0, 1 and 1, respectively, these numbers are removed from the technical terms. For example,

$$S_p^*(\alpha) = S_p^*(\alpha)_1, \quad K_p(\alpha) = K_p(\alpha)_1, \quad S^*(\alpha)_r = S_1^*(\alpha)_r,$$

$$S^*(\alpha) = S_1^*(\alpha)_1, \quad K(\alpha)_r = K_1(\alpha)_r, \quad C_p(\alpha, M_\beta) = C_p(\alpha, M_\beta)_1,$$

$$S^* = S_1^*(0)_1, \quad K = K_1(0)_1, \quad C = C_1(0, M_1)_1.$$

A function $f(z)$ in the classes S^*, K and C is said to be starlike, convex and close-to-convex, respectively.

2. The radii of starlikeness

In order to get our results, we here have to recall Lemma 2.A and prove Lemma 2.1.

Lemma 2.A (Nunokawa and Causey [1]). *Let β be $\beta > 0$. If $p(z) \in M(\beta)$, then*

$$\left| \frac{p'(z)}{p(z)} \right| \leq \frac{2\beta}{1 - |z|^2} \qquad (z \in U). \tag{2.1}$$

Lemma 2.1. *Let p and α be $p \in N$ and $0 \leq \alpha < p$, respectively.*

If $g(z) \in S_p^*(\alpha)$, *then*

$$(2.2) \qquad \mathrm{Re}\left\{ \frac{z\,g'(z)}{g(z)} \right\} \geq (p-\alpha)\frac{1-|z|}{1+|z|} + \alpha \qquad (z \in U).$$

Proof. Defining the functions $h(z)$ and $h_0(z)$ by

$$(2.3) \qquad h(z) = \frac{z\,g'(z)}{p\,g(z)} \quad \text{and} \quad h_0(z) = \left(1 - \frac{\alpha}{p}\right)\frac{1-z}{1+z} + \frac{\alpha}{p},$$

respectively, we have

$$h(z),\ h_0(z) \in M, \quad h(0) = h_0(0) \quad \text{and} \quad \mathrm{Re}\ h(z) > \frac{\alpha}{p},$$

because of $g(z) \in S_p^*(\alpha)$. Since the function $h_0(z)$ is univalent in U and maps the unit disk U onto $\mathrm{Re}\ w > \frac{\alpha}{p}$, we obtain

$$\left| h_0^{-1}(h(z)) \right| \leq |z| \qquad (z \in U)$$

by using Schwarz's lemma. This inequality shows that the image of the unit disk U by $h(z)$ have to be in the disk whose diameter end points are

$$\left(1 - \frac{\alpha}{p}\right)\frac{1-|z|}{1+|z|} + \frac{\alpha}{p} \quad \text{and} \quad \left(1 - \frac{\alpha}{p}\right)\frac{1+|z|}{1-|z|} + \frac{\alpha}{p}.$$

This completes the proof of Lemma 2.1. *q.e.d.*

Now, we have

Theorem 2.1. *Let* p, j, α, β *and* γ *be* $p \in N$, $j = 0, 1, 2, \cdots, p-1$, $0 \leq \alpha < p-j$, $\beta > 0$ *and* $0 \leq \gamma < p-j$, *respectively. If a function* $f(z)$ *is in the class* A_p *and*

$$\frac{f^{(j)}(z)}{g^{(j)}(z)} \in M(\beta)$$

for some $g(z) \in A_p$ *such that*

$$\frac{(p-j)!}{p!} g^{(j)}(z) \in S^*_{p-j}(\alpha),$$

then

$$\frac{(p-j)!}{p!} f^{(j)}(z) \in S^*_{p-j}(\gamma)_r,$$

where

$$(2.4)\quad \begin{cases} r = \dfrac{p-j-\alpha+\beta-\sqrt{A}}{p-j-2\alpha+\gamma} & \text{if } p-j-2\alpha+\gamma > 0, \\[2ex] r = \dfrac{p-j-\alpha+\beta+\sqrt{A}}{p-j-2\alpha+\gamma} & \text{if } p-j-2\alpha+\gamma < 0, \\[2ex] r = \dfrac{p-j-\alpha}{p-j-\alpha+\beta} & \text{if } p-j-2\alpha+\gamma = 0, \end{cases}$$

and

$$A = (\alpha-\beta-\gamma)^2 + 2\beta\,(p-j-\gamma).$$

The result is sharp for the function $f(z)$ *defined by*

$$(2.5)\qquad f(z) = \frac{z^p}{(1-z)^{2(p-\alpha)}}\left(\frac{1+z}{1-z}\right)^{\beta} \qquad \text{as} \quad j = 0,$$

$$(2.6)\quad f(z) = \int_0^z\int_0^{\xi_j}\cdots\int_0^{\xi_2} \frac{p!\,\xi_1^{p-j}}{(p-j)!\,(1-\xi_1)^{2(p-j-\alpha)}}\left(\frac{1+\xi_1}{1-\xi_1}\right)^{\beta} d\xi_1\cdots d\xi_{j-1}d\xi_j$$

$$\text{as} \quad j = 1, 2, \cdots, p-1,$$

at $z = -|z|$.

Proof. Defining the function $p(z)$ by

$$(2.7)\qquad p(z) = \frac{f^{(j)}(z)}{g^{(j)}(z)},$$

we have $p(z) \in M(\beta)$. Since

(2.8) $$\frac{p'(z)}{p(z)} = \frac{f^{(j+1)}(z)}{f^{(j)}(z)} - \frac{g^{(j+1)}(z)}{g^{(j)}(z)},$$

we see, using Lemma 2.A, that

(2.9) $$\left| \frac{z\,f^{(j+1)}(z)}{f^{(j)}(z)} - \frac{z\,g^{(j+1)}(z)}{g^{(j)}(z)} \right| \leq \frac{2\beta\,|z|}{1-|z|^2} \qquad (\,z \in U\,).$$

The function $\frac{(\,p-j\,)!}{p!}g^{(j)}(z) \in S^*_{p-j}(\alpha)$ satisfies

(2.10) $$\mathrm{Re}\left\{ \frac{z\,g^{(j+1)}(z)}{g^{(j)}(z)} \right\} \geq (\,p-j-\alpha\,)\frac{1-|z|}{1+|z|} + \alpha \qquad (\,z \in U\,),$$

by Lemma 2.1. Therefore, it follows from (2.9) and (2.10) that

(2.11) $$\begin{aligned} \mathrm{Re}\left\{ \frac{z\,f^{(j+1)}(z)}{f^{(j)}(z)} \right\} &\geq \mathrm{Re}\left\{ \frac{z\,g^{(j+1)}(z)}{g^{(j)}(z)} \right\} - \frac{2\beta\,|z|}{1-|z|^2} \\ &\geq (\,p-j-\alpha\,)\frac{1-|z|}{1+|z|} + \alpha - \frac{2\beta\,|z|}{1-|z|^2} \\ &> \gamma, \text{ in } U_r. \end{aligned}$$

q. e. d.

We here obtain two corollaries. Putting $j = 0$ in Theorem 2.1, we have Corollary 2.1.

Corollary 2.1. *Let* p, α, β *and* γ *be* $p \in N$, $0 \leq \alpha < p$, $\beta > 0$ *and* $0 \leq \gamma < p$, *respectively. If a function* $f(z)$ *is in the class* A_p *and*

$$\frac{f(z)}{g(z)} \in M(\beta)$$

for some $g(z) \in S^*_p(\alpha)$, *then*

$$f(z) \in S_p^*(\gamma)_r,$$

where

$$(2.12)\quad \begin{cases} r = \dfrac{p - \alpha + \beta - \sqrt{B}}{p - 2\alpha + \gamma} & \text{if} \quad p - 2\alpha + \gamma > 0, \\ r = \dfrac{p - \alpha + \beta + \sqrt{B}}{p - 2\alpha + \gamma} & \text{if} \quad p - 2\alpha + \gamma < 0, \\ r = \dfrac{p - \alpha}{p - \alpha + \beta} & \text{if} \quad p - 2\alpha + \gamma = 0, \end{cases}$$

and

$$B = (\alpha - \beta - \gamma)^2 + 2\beta\,(p - \gamma).$$

The result is sharp for the function $f(z)$ *defined by* (2.5) *at* $z = -|z|$.

Putting $p = 1$ in Corollary 2.1, we have Corollary 2.2.

Corollary 2.2. *Let* α, β *and* γ *be* $0 \leq \alpha < 1$, $\beta > 0$ *and* $0 \leq \gamma < 1$, *respectively. If a function* $f(z)$ *is in the class* A *and*

$$\frac{f(z)}{g(z)} \in M(\beta)$$

for some $g(z) \in S^*(\alpha)$, *then*

$$f(z) \in S^*(\gamma)_r,$$

where

$$(2.13)\quad \begin{cases} r = \dfrac{1 - \alpha + \beta - \sqrt{C}}{1 - 2\alpha + \gamma} & \text{if} \quad 1 - 2\alpha + \gamma > 0, \\ r = \dfrac{1 - \alpha + \beta + \sqrt{C}}{1 - 2\alpha + \gamma} & \text{if} \quad 1 - 2\alpha + \gamma < 0, \\ r = \dfrac{1 - \alpha}{1 - \alpha + \beta} & \text{if} \quad 1 - 2\alpha + \gamma = 0, \end{cases}$$

and

$$C = (\alpha - \beta - \gamma)^2 + 2\beta\ (1 - \gamma).$$

The result is sharp for the function $f(z)$ *defined by*

$$(2.14) \qquad f(z) = \frac{z}{(1-z)^{2(1-\alpha)}} \left(\frac{1+z}{1-z} \right)^{\beta}$$

at $z = -|z|$.

Remark 2.1. Taking $\alpha = 0$ in Corollary 2.2, we have the corresponding result due to Yaguchi, Obradović, Nunokawa and Owa [3]. Furthermore, taking $\gamma = 0$ and $\beta = 2$ in Corollary 2.2, we have the corresponding result due to Yaguchi and Nunokawa [2].

3. The radius of convexity

Noting that $f(z) \in K_p(\alpha)$ if and only if $zf'(z) \in S_p^*(\alpha)$, we get the following result with the aid of Theorem 2.1.

Theorem 3.1. *Let* p, j, α, β *and* γ *be in the same conditions as in Theorem 2.1. If a function* $f(z)$ *is in the class* A_p *and*

$$\frac{f^{(j+1)}(z)}{g^{(j+1)}(z)} \in M(\beta)$$

for some $g(z) \in A_p$ *such that*

$$\frac{(p-j)!}{p!} g^{(j)}(z) \in K_{p-j}(\alpha),$$

then

$$\frac{(p-j)!}{p!} f^{(j)}(z) \in K_{p-j}(\gamma)_r,$$

where r *is given by (2.4). The result is sharp for the function* $f(z)$ *defined by*

$$(3.1)\quad f(z)=\int_0^z\int_0^{\xi_j}\cdots\int_0^{\xi_1}\frac{p!\qquad \xi_0^{p-j-1}}{(p-j-1)!(1-\xi_0)^{2(p-j-\alpha)}}\left(\frac{1+\xi_0}{1-\xi_0}\right)^{\beta}d\xi_0\cdots d\xi_{j-1}d\xi_j,$$

at $z=-|z|$.

Proof. Defining the functions $F(z)$ and $G(z)$ by

$$F(z)=\frac{(p-j-1)!}{p!}z\,f^{(j+1)}(z)$$

and

$$G(z)=\frac{(p-j-1)!}{p!}z\,g^{(j+1)}(z),$$

respectively. We have

$$F(z)\in A_{p-j},\quad G(z)\in S^*_{p-j}(\alpha)\quad \text{and}\quad \frac{F(z)}{G(z)}\in M(\beta).$$

By Corollary 2.1, we obtain that $F(z)\in S^*_{p-j}(\gamma)_r$, where r is given by (2.2). Therefore $\frac{(p-j)!}{p!}f^{(j)}(z)$ is $(p-j)$-valently convex of order γ in U_r. *q.e.d.*

Putting $j=0$ in Theorem 3.1, we have Corollary 3.1.

Corollary 3.1. *Let* p, α, β *and* γ *be in the same conditions as in Corollary 2.1. If a function* $f(z)$ *in* A_p *is in the class* $C_p(\alpha,M_\beta)$, *then* $f(z)\in K_p(\gamma)_r$, *where* r *is given by (2.12). The result is sharp for the function* $f(z)$ *defined by*

$$(3.2)\qquad f(z)=\int_0^z\frac{p\,\xi^{p-1}}{(1-\xi)^{2(p-\alpha)}}\left(\frac{1+\xi}{1-\xi}\right)^{\beta}d\xi,$$

at $z=-|z|$.

Putting $p=1$ in Corollary 3.1, we have Corollary 3.2.

Corollary 3.2. *Let α, β and γ be in the same conditions as in Corollary 2.2. If a function $f(z)$ in the class A is in the class $C(\alpha, M_\beta)$, then $f(z) \in K(\gamma)_r$, where r is given by (2.13). The result is sharp for the function $f(z)$ defined by*

$$(3.3) \qquad f(z) = \int_0^z \frac{1}{(1-\xi)^{2(1-\alpha)}} \left(\frac{1+\xi}{1-\xi} \right)^\beta d\xi$$

at $z = -|z|$.

Putting $\beta = 1$ in Corollary 3.2, we have Corollary 3.3.

Corollary 3.3. *If a function $f(z)$ in the class A is close-to-convex of order α $(0 \leq \alpha < 1)$, then $f(z)$ is convex of order γ in U_r, where*

$$(3.4) \qquad \begin{cases} r = \dfrac{2-\alpha-\sqrt{D}}{1-2\alpha+\gamma} & \text{if} \quad 1-2\alpha+\gamma > 0, \\[2ex] r = \dfrac{2-\alpha+\sqrt{D}}{1-2\alpha+\gamma} & \text{if} \quad 1-2\alpha+\gamma < 0, \\[2ex] r = \dfrac{1-\alpha}{2-\alpha} & \text{if} \quad 1-2\alpha+\gamma = 0, \end{cases}$$

and

$$D = (\alpha-\gamma)^2 - 2\alpha + 3.$$

The result is sharp for the function $f(z)$ defined by

$$(3.5) \qquad f(z) = \frac{1}{(2\alpha-1)(1-\alpha)} \left(\frac{\alpha-(1-\alpha)z}{(1-z)^{2(1-\alpha)}} - \alpha \right) \qquad \left(\alpha \neq \frac{1}{2} \right)$$

$$(3.6) \qquad f(z) = \frac{2z}{1-z} + \log(1-z) \qquad \left(\alpha = \frac{1}{2} \right)$$

at $z = -|z|$.

Putting $\alpha = 0$ in Corollary 3.3, we have Corollary 3.4.

Corollary 3.4. *If a function $f(z)$ in the class A is close-to-convex, then $f(z)$ is convex of order γ in U_r,*

where $r = \dfrac{2 - \sqrt{\gamma^2 + 3}}{1 + \gamma}$.

The result is sharp for the Koebe function

$$f(z) = \frac{z}{(1 - z)^2}$$

at $z = -|z|$.

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