

# Univalence of an integral operator defined by generalized operators

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**Abstract**—In this paper we define generalized differential operators from some well-known operators on the class  $A$  of analytic functions in the unit disk  $U = \{z \in C : |z| < 1\}$ . New classes containing these operators are investigated. Also univalence of integral operator is considered.

**Keywords**—Univalent functions, Integral operators, Differential operators.

## I. INTRODUCTION

Let  $H$  be the class of analytic functions in  $U = \{z \in C : |z| < 1\}$  and  $H[a, n]$  be the subclass of  $H$  consisting of functions of the form  $f(z) = a + a_n z^n + a_{n+1} z^{n+1} + \dots$

Let  $A$  be the subclass of  $H$  consisting of functions of the form

$$f(z) = z + \sum_{n=2}^{\infty} a_n z^n \quad (1)$$

Let  $\hat{C}_\theta(\alpha)$  denote the class of functions  $f \in A$  satisfying the following

$$\Re \left\{ e^{i\theta} \left( \frac{z f''(z)}{f'(z)} + 1 \right) \right\} > \alpha \cos \theta$$

for

$$\left( 0 \leq \alpha < 1, -\frac{\pi}{2} < \theta < \frac{\pi}{2}, z \in U \right).$$

If  $\theta = 0$ , the class  $\hat{C}_\theta(\alpha) = \hat{C}(\alpha)$  is the well-known convex functions of order  $\alpha$ . If  $f(z) = z + \sum_{n=2}^{\infty} a_n z^n \in A$  and  $g(z) = z + \sum_{n=2}^{\infty} b_n z^n \in A$  then the Hadamard product or convolution of  $f$  and  $g$  is defined by

$$(f * g)(z) = z + \sum_{n=2}^{\infty} a_n b_n z^n, \quad z \in U.$$

And for several functions  $f_1(z), \dots, f_m(z) \in A$

$$f_1(z) * \dots * f_m(z) = z + \sum_{n=2}^{\infty} (a_{1n} \dots a_{mn}) z^n, \quad z \in U$$

Our aim is to use the Hadamard product of  $K$ -th order to define generalized differential operators. For  $f \in A$  of the form (1) first we define the following generalized differential operator

$$D^0 f(z) = f(z)$$

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$$D_{\alpha, \beta, \lambda, \delta}^1 f(z) = [1 - (\lambda - \delta)(\beta - \alpha)] f(z) + (\lambda - \delta)(\beta - \alpha) z f'(z)$$

$$= z + \sum_{n=2}^{\infty} [(\lambda - \delta)(\beta - \alpha)(n - 1) + 1] a_n z^n$$

⋮

$$D_{\alpha, \beta, \lambda, \delta}^k f(z) = D_{\alpha, \beta, \lambda, \delta}^1 \left( D_{\alpha, \beta, \lambda, \delta}^{k-1} f(z) \right)$$

$$D_{\alpha, \beta, \lambda, \delta}^k f(z) = z + \sum_{n=2}^{\infty} [(\lambda - \delta)(\beta - \alpha)(n - 1) + 1]^k a_n z^n, \quad (2)$$

for  $\alpha \geq 0, \beta \geq 0, \lambda \geq 0, \delta \geq 0, \lambda > \delta, \beta > \alpha$  and  $k \in \{0, 1, 2, \dots\}$ .

Remark : (i) When  $\alpha = 0, \delta = 0, \lambda = 1, \beta = 1$  we get Salagean differential operator (see [5]).

(ii) When  $\alpha = 0$  we get M. Darus and R. Ibrahim differential operator (see [3]).

(iii) And when  $\alpha = 0, \delta = 0, \beta = 1$  we get Al-Oboudi differential operator (see [1]).

**Definition 1.1:** A function  $f \in A$  in the class  $\hat{C}_\theta^k(\alpha)$  where  $-\frac{\pi}{2} < \theta < \frac{\pi}{2}, 0 \leq \alpha < 1$ , if it satisfies the following inequality:

$$\Re \left\{ e^{i\theta} \left( \frac{z \left[ D_{\alpha, \beta, \lambda, \delta}^k f(z) \right]''}{\left[ D_{\alpha, \beta, \lambda, \delta}^k f(z) \right]'} + 1 \right) \right\} > \alpha \cos \theta \quad (3)$$

**Definition 1.2:** For  $m \in N \cup \{0\}, j \in \{1, 2, 3, \dots, m\}, s_j \in C$  we introduce the integral operator

$$F_{s_1 \dots s_m}(z) = \int_0^z [t f_1'(t)]^{s_1} \dots [t f_m'(t)]^{s_m} dt, \quad (t > 0, s_j > 0) \quad (4)$$

when  $t = 1$ , the operator  $F_{s_1 \dots s_m}(z)$  reduced to an integral operator

$$F_s(z) = \int_0^z [f_1'(t)]^{s_1} \dots [f_m'(t)]^{s_m} dt \quad (s_j > 0)$$

recently introduced and studied by D.Breaz, S.Owa, and N.Breaz in [2]. See also similar work given by [4] and [6].

In this paper, we consider the following integral operator which involving the generalized operator (2) and study its properties on the class  $\hat{C}_\theta(\alpha)$ .

**Definition 1.3:** for  $m \in \{0, 1, 2, \dots\}$ ,  $s_j > 0$ ,  $f \in A$  we define an integral operator  $F_{s_1 \dots s_m}^k(z)$  as the following:

$$F_{s_1 \dots s_m}^k(z) = \int_0^z \left[ t (D_{\alpha, \beta, \lambda, \delta}^k f_1(t))' \right]^{s_1} \dots \left[ t (D_{\alpha, \beta, \lambda, \delta}^k f_m(t))' \right]^{s_m} dt, \quad (5)$$

for

$$(t > 0, t \in U).$$

**Lemma 1.4:** If  $f \in A$  satisfies the inequality

$$(1 - |z|^2) \left| \frac{z f''(z)}{f'(z)} \right| \leq 1 \quad \text{for all } z \in U$$

then the function  $f$  is univalent in  $U$ .

## II. MAIN RESULTS

We begin with the following theorem:

**Theorem 2.1:** Let  $f_j \in A$ ,  $s_j \in C$ ,  $j \in \{1, 2, \dots, m\}$ . If

$$\left| \frac{z [D_{\alpha, \beta, \lambda, \delta}^k f_j(z)]''}{[D_{\alpha, \beta, \lambda, \delta}^k f_j(z)]'} + 1 \right| \leq 1,$$

$|s_1| + |s_2| + \dots + |s_m| \leq 1$ ,  $z \in U$ , then  $F_{s_1 \dots s_m}^k(z)$  given by (5) is univalent.

**Proof:** From (5) we obtain

$$[F_{s_1 \dots s_m}^k(z)]' = \left[ z (D_{\alpha, \beta, \lambda, \delta}^k f_1(z))' \right]^{s_1} \dots \left[ z (D_{\alpha, \beta, \lambda, \delta}^k f_m(z))' \right]^{s_m}$$

for  $z > 0$ ,  $z \in U$  which implies that

$$\ln [F_{s_1 \dots s_m}^k(z)]' = s_1 \ln \left[ z (D_{\alpha, \beta, \lambda, \delta}^k f_1(z))' \right] + \dots + s_m \ln \left[ z (D_{\alpha, \beta, \lambda, \delta}^k f_m(z))' \right]$$

and taking the derivative for the above equality, we have

$$\frac{[F_{s_1 \dots s_m}^k(z)]''}{[F_{s_1 \dots s_m}^k(z)]'} = s_1 \left[ \frac{(D_{\alpha, \beta, \lambda, \delta}^k f_1(z))''}{(D_{\alpha, \beta, \lambda, \delta}^k f_1(z))'} + \frac{1}{z} \right] + \dots + s_m \left[ \frac{(D_{\alpha, \beta, \lambda, \delta}^k f_m(z))''}{(D_{\alpha, \beta, \lambda, \delta}^k f_m(z))'} + \frac{1}{z} \right]. \quad (6)$$

By multiplying the relation (6) with  $z$  we obtain

$$\frac{z [F_{s_1 \dots s_m}^k(z)]''}{[F_{s_1 \dots s_m}^k(z)]'} = s_1 \left[ \frac{z (D_{\alpha, \beta, \lambda, \delta}^k f_1(z))''}{(D_{\alpha, \beta, \lambda, \delta}^k f_1(z))'} + 1 \right] + \dots + s_m \left[ \frac{z (D_{\alpha, \beta, \lambda, \delta}^k f_m(z))''}{(D_{\alpha, \beta, \lambda, \delta}^k f_m(z))'} + 1 \right] \quad (7)$$

On multiplying the modulus of equation (7) by  $(1 - |z|^2)$ , we obtain

$$(1 - |z|^2) \left| \frac{z [F_{s_1 \dots s_m}^k(z)]''}{[F_{s_1 \dots s_m}^k(z)]'} \right| \leq (1 - |z|^2) \left[ |s_1| \left| \frac{z (D_{\alpha, \beta, \lambda, \delta}^k f_1(z))''}{(D_{\alpha, \beta, \lambda, \delta}^k f_1(z))'} + 1 \right| + \dots + |s_m| \left| \frac{z (D_{\alpha, \beta, \lambda, \delta}^k f_m(z))''}{(D_{\alpha, \beta, \lambda, \delta}^k f_m(z))'} + 1 \right| \right] \leq (1 - |z|^2) [|s_1| + |s_2| + \dots + |s_m|] \leq |s_1| + |s_2| + \dots + |s_m| \leq 1$$

From Lemma (4), we have that  $F_{s_1 \dots s_m}^k(z)$  is univalent.

Taking  $k = 0$  in Theorem 2.1, we have

**Corollary 2.2:** If  $f_j \in A$ ,  $s_j \in C$ ,  $j = \{1, 2, \dots, m\}$ . If

$$\left| \frac{z f_j''(z)}{f_j'(z)} + 1 \right| \leq 1, \quad |s_1| + |s_2| + \dots + |s_m| \leq 1, \quad z \in U$$

then  $F_{s_1 \dots s_m}(z)$  given by (4) is univalent.

**Theorem 2.3:** Let  $s_1, s_2, \dots, s_m$  be real number with the properties  $s_j > 0$  for  $j \in \{1, 2, \dots, m\}$  and

$$0 \leq \sum_{j=1}^m s_j \alpha_j + 1 < 1$$

then the integral operator  $F_{s_1 \dots s_m}^k(z) \in \hat{C}_\theta^k(\gamma)$  where

$$\gamma = \sum_{j=1}^m s_j \alpha_j + 1, \quad -\frac{\pi}{2} < \theta < \frac{\pi}{2}.$$

**Proof:** Using (7), we obtain

$$\frac{z [F_{s_1 \dots s_m}^k(z)]''}{[F_{s_1 \dots s_m}^k(z)]'} = \sum_{j=1}^m s_j \left[ \frac{z (D_{\alpha, \beta, \lambda, \delta}^k f_j(z))''}{(D_{\alpha, \beta, \lambda, \delta}^k f_j(z))'} + 1 \right] \quad (8)$$

the relation (8) is the equivalent to

$$\frac{z [F_{s_1 \dots s_m}^k(z)]''}{[F_{s_1 \dots s_m}^k(z)]'} + 1 = \sum_{j=1}^m s_j \left[ \frac{z (D_{\alpha, \beta, \lambda, \delta}^k f_j(z))''}{(D_{\alpha, \beta, \lambda, \delta}^k f_j(z))'} + 1 \right] + 1 \quad (9)$$

by multiplying the relation (9) by  $e^{i\theta}$  we get

$$\Re \left\{ e^{i\theta} \left( \frac{z [F_{s_1 \dots s_m}^k(z)]''}{[F_{s_1 \dots s_m}^k(z)]'} + 1 \right) \right\} = \sum_{j=1}^m s_j \Re \left\{ e^{i\theta} \left( \frac{z (D_{\alpha, \beta, \lambda, \delta}^k f_j(z))''}{(D_{\alpha, \beta, \lambda, \delta}^k f_j(z))'} + 1 \right) \right\} + \Re e^{i\theta} \quad (10)$$

since each  $f_j \in \hat{C}_\theta(\alpha_j)$  for  $j \in \{1, 2, 3, \dots, m\}$  by using (3) in (10) we have

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$$\Re \left\{ e^{i\theta} \left( \frac{z [F_{s_1 \dots s_m}^k(z)]''}{[F_{s_1 \dots s_m}^k(z)]'} + 1 \right) \right\} > \cos \theta \left( \sum_{j=1}^m s_j \alpha_j + 1 \right),$$

$$-\frac{\pi}{2} < \theta < \frac{\pi}{2}.$$

Since by hypothesis  $0 \leq \sum_{j=1}^m s_j \alpha_j + 1 < 1$ , we obtain

$$F_{s_1 \dots s_m}^k(z) \in \hat{C}_\theta^k(\gamma) \text{ where } \gamma = \sum_{j=1}^m s_j \alpha_j + 1, \quad -\frac{\pi}{2} < \theta < \frac{\pi}{2}.$$

By taking  $k = 0$  in Theorem 2.3 we have

*Corollary 2.4:* Let  $s_1, s_2, \dots, s_m$  be real number with the properties  $s_j > 0$  for  $j \in \{1, 2, 3, \dots, m\}$  and

$$0 \leq \sum_{j=1}^m s_j \alpha_j + 1 < 1$$

If  $f_j(z) \in \hat{C}_\theta(\alpha_j)$  for  $j \in \{1, 2, \dots, m\}$ , then  $F_{s_1 \dots s_m}(z)$  given by (4) belongs to  $\hat{C}_\theta(\gamma)$  where  $\gamma = \sum_{j=1}^m s_j \alpha_j + 1$ ,  $-\frac{\pi}{2} < \theta < \frac{\pi}{2}$ .

### III. CONCLUSION

Univalence condition in the area of studies is very important. The class of functions introduced needed to be varified its univalency. The criteria is indeed proven. The operator given can also be extended further and can generate more new results.

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